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Multiyear Synthesis of the Aquatic Vegetation Component from 1991 to 2002 for the Long Term Resource Monitoring Program

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by

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Contents

Tables

Number

Figures

Preface

This report summarizes monitoring activities of the aquatic vegetation component of the Long Term Resources Monitoring Program (LTRMP) of the Upper Mississippi River System (UMRS) from 1991 to 2002. The LTRMP was authorized under the Water Resources Development Act of 1986 (Public Law 99 662) as an element of the U.S. Army Corps of Engineers Environmental Management Program. The LTRMP is implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem, given its multiuse character. The long term goals of the program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

This report is to provide a 12-year summary of data regarding the status and trends of aquatic vegetation within the UMRS. In this report we present the results of both transect surveys (conducted between 1991 and 2000) and stratified random sampling surveys (conducted between 1998 and 2002) of the aquatic vegetation resources of the UMRS and provide an assessment of the effects of a Habitat Restoration and Enhancement Project in Pool 8. Work was performed by field station personnel from Minnesota, Wisconsin, Iowa, Illinois, and Missouri under the direction of staff from the Upper Midwest Environmental Sciences Center. This document satisfies Task 2.2.4 under Goal 2, Monitor Resource Change of the Operating Plan (U.S. Fish and Wildlife Service 1993). This document was developed with funding provided by the Long Term Resource Monitoring Program.

Multiyear Synthesis of the Aquatic Vegetation Component from 1991 to 2002 for the Long Term Resource Monitoring Program

by

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Abstract: Aquatic vegetation data were collected in the Upper Mississippi River System (UMRS) under the Long Term Resource Monitoring Program (LTRMP). From 1991 to 2002, five reaches were surveyed every year (key pools), and another five reaches were surveyed once (outpools). The study design changed from a protocol involving sampling along transects (1991–2000) to a protocol incorporating stratified random sampling (1998–2002) with concurrent sampling under both protocols in 1998–2000. The frequency of occurrence of plants revealed no synchronous trends among three key pools (Pools 4, 8, and 13) supporting sizable submersed aquatic vegetation beds. Submersed aquatic vegetation in upper Pool 4 declined steadily between 1991 and 2002. Submersed aquatic vegetation in lower Pool 4 declined between 1991 and 1996 and thereafter recovered moderately. Submersed aquatic vegetation in Pool 8 increased between 1991 and 1999, which probably was a recovery process from a reported sudden collapse after the 1987–1989 drought. Submersed aquatic vegetation in Pool 13 demonstrated a high degree of stability during the period of monitoring despite drastic fluctuations between spring and summer sampling in some years. Water turbidity and water level fluctuation were strongly correlated with the longitudinal pattern of submersed aquatic vegetation distribution in the UMRS. Pools with clearer water and less fluctuating water levels supported more submersed aquatic vegetation. The LTRMP key pools represented a wide spectrum of the UMRS habitats. The habitat rehabilitation and enhancement project (HREP) at Stoddard Bay in Pool 8 effectively stimulated colonization by aquatic vegetation.

Key words: Aquatic vegetation, rooted floating-leaf, Illinois River, key pools, Long Term Resource Monitoring Program, Upper Mississippi River, outpools, submersed vegetation

Chapter 1: Introduction

Aquatic vegetation refers to plants with leaves and stems growing above, on, or under the surface of the water and are usually anchored to the sediments by their roots. Aquatic vegetation in the Upper Mississippi River System (UMRS; Figure 1.1) is desirable because of its many values, most notably as food for migratory waterfowl (Korschgen et al. 1988) and habitat for fish. The construction of a series of locks and dams in the 1930s in the Upper Mississippi River (UMR) to create a 9-foot deep navigation channel also created vast shallow backwaters ideal for aquatic vegetation. Growth of aquatic vegetation was categorized as excellent inside the Upper Mississippi Wildlife and Fish Refuge (Pools 4 through 14) for three decades before symptoms of deterioration associated with permanent impoundment became apparent (Green 1984). A widespread and sudden decline of American wildcelery (*Vallisneria americana* Michx.) in Pools 5 through 19 during the late 1980s and early 1990s elevated the concern that the UMR might be on the verge of a drastic degradation as occurred in the Illinois River (Rogers and Theiling 1998).

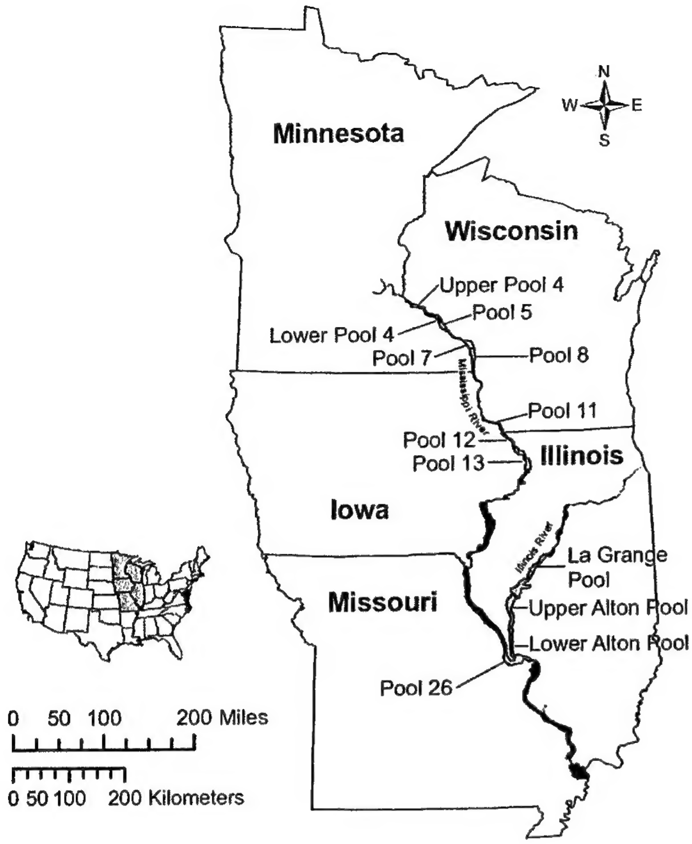


Figure 1.1. Upper Mississippi River System pool sampled for aquatic vegetation, Long Term Resource Monitoring Program.

The Illinois River harbored abundant aquatic vegetation in its expansive backwaters until the early twentieth century (Mills et al. 1966; Bellrose et al. 1979). The completion of the Chicago Sanitary and Ship Canal in 1900 diverted water from Lake Michigan and sewage from Chicago down the Illinois River and raised the water levels several feet causing a decline in aquatic vegetation. Aquatic vegetation increased in the late 1920s and early 1930s because of the construction of many sewage treatment plants along the river and a reduction in the amount of water diverted from Lake Michigan in 1939. A collapse of vegetation abundance and fingernail clam populations in the mid-1950s were important indicators of ecological degradation of the Illinois River (Sparks 1984).

Vegetation sampling was first included in the Long Term Resource Monitoring Program (LTRMP) in 1989. Terrestrial and aquatic plant communities encountered along transect lines laid across the entire width of the floodplain in Pools 8, 13, and 26 of the UMR were quantified and mapped. In 1990, additional transects were established in Pool 4 of the UMR and La Grange Pool of the Illinois River. In all five pools, quadrats were selected for quantitative sampling at 50-meter intervals along each transect and data on species present were collected (Langrehr 1992; Peitzmeier-Romano et al. 1992; Shay and Gent 1992).

In 1991, a programmatic decision was made to focus on submersed aquatic vegetation (SAV) for three major reasons. First, SAV was the most dynamic plant life form in the UMR. Second, SAV was of greatest concern to river managers because of a recent decline, and third, data on the vegetation above the water surface (emergent and rooted floatingleaf species) were collected using aerial photography. The primary objective of sampling along transects was to describe status and trends of submersed aquatic vegetation in selected backwaters (Figures 1.2–1.6; Appendix A) in Pools 4, 8, 13, and 26 and the La Grange Pool (Rogers et al. 1998), although data on the presence of rooted floating-leaf vegetation were also recorded. The Open River reach, below St Louis, Missouri, was not sampled because it consisted of large channels not supporting sizable and stable submersed aquatic vegetation beds. Vegetation was sampled along transects once in spring and once in summer (Rogers and Owens 1995). Sampling locations (boat stops) along transects were spaced at either 15- or 30-m intervals. Lengths of transects varied by location. In general, sampling along a transect was terminated when the water depth at sampling locations exceeded 2.5 m for an extended distance (e.g., into open water). However, in situations where the distance across open water to areas of SAV was minimal, sampling continued until either depth again increased beyond 2.5 m for an extended distance or a shoreline was reached. Transect sampling of selected backwaters continued through 2000.

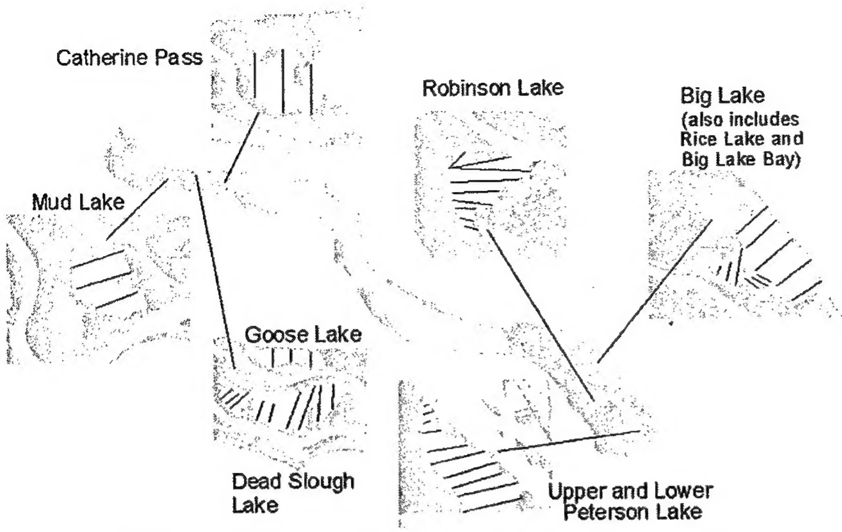


Figure 1.2. Location and arrangement of transects in Pool 4, Upper Mississippi River.

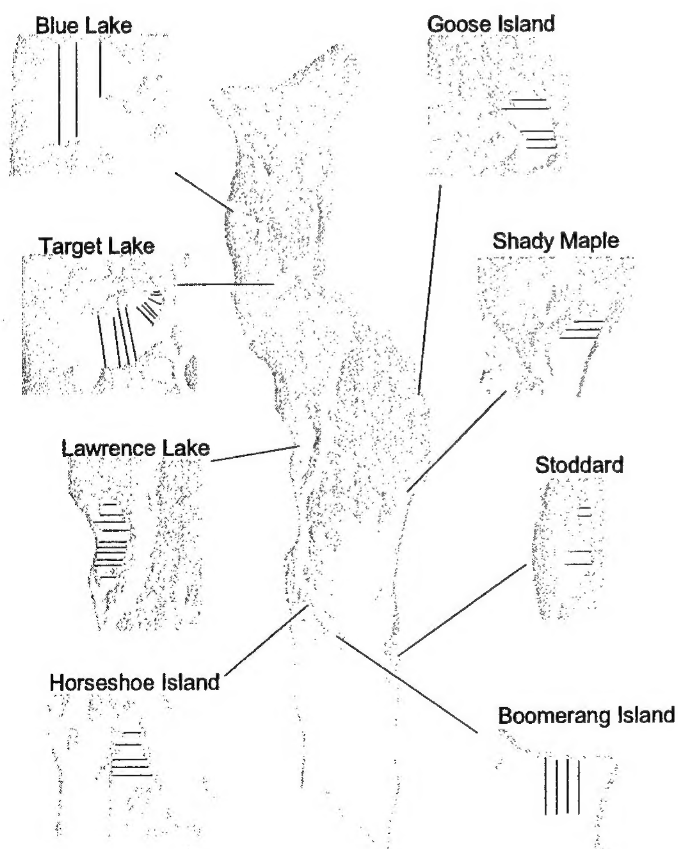


Figure 1.3. Location and arrangement of transects in Pool 8, Upper Mississippi River.

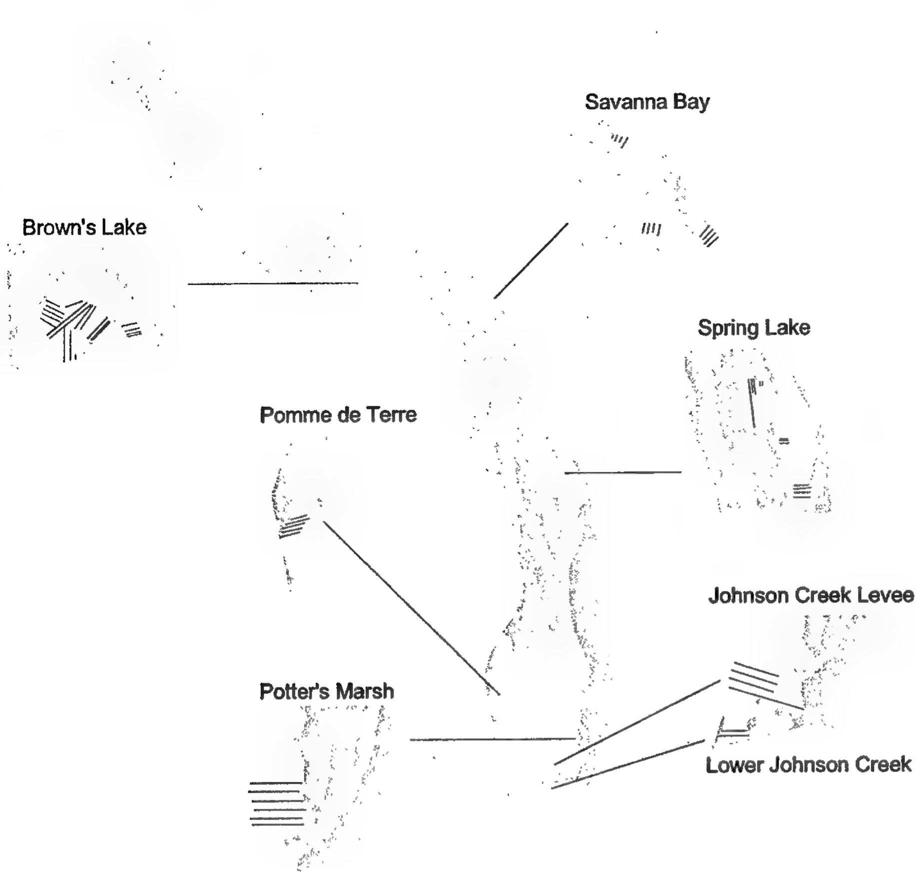


Figure 1.4. Location and arrangement of transects in Pool 13, Upper Mississippi River.

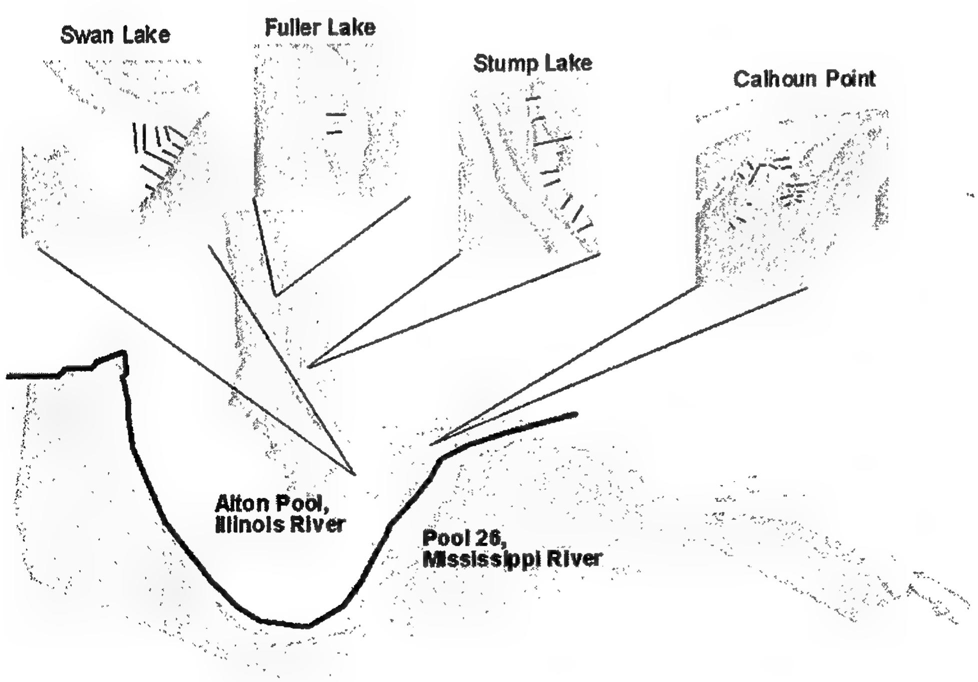


Figure 1.5. Location and arrangement of transects in Alton Pool, Illinois River.

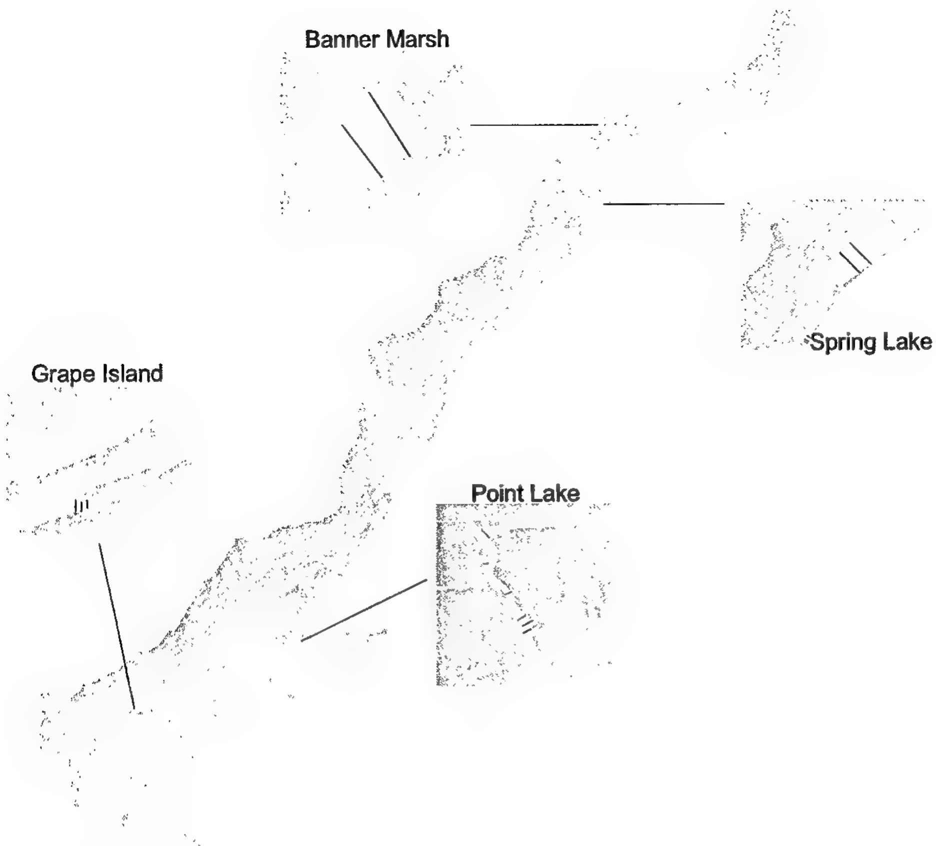


Figure 1.6. Location and arrangement of transects in La Grange Pool, Illinois River.

In 1998, a stratified random sampling (SRS) protocol was begun (Yin et al. 2000b) to collect data from all shallow water areas where SAV could potentially exist. The transect sampling was then discontinued after three concurrent sampling seasons with the SRS protocol. The LTRMP Onalaska Field Station (Wisconsin Department of Natural Resources) received a grant from the U.S. Environmental Protection Agency funding one additional season of transect sampling in Pool 8. From 1998 to 2002, SRS was conducted annually in Pools 4, 8, 13, and 26 of the UMR and in the lower 12 miles of the Alton Pool and entire La Grange Pool of the Illinois River (Figure 1.1). Other reaches were sampled once during the same period to evaluate the longitudinal heterogeneity of aquatic vegetation outside the key pools (hereafter referred to as "outpool" sampling as opposed to "key" pool sampling). These included Pool 11 in 2001 and Pools 5, 7, and 12 and upper Alton Pool (excluding the lower 12 miles) in 2002 (Table 1).

We analyzed the transect protocol data and the SRS protocol data for information that would improve our understanding of the UMRS ecosystem and shed light on the pros and cons of environmental engineering for habitat restoration. The main body of this report consists of chapters addressing four separate topics. The status and trends of submersed aquatic vegetation in the key pools are evaluated in Chapter 2. Similarities between key pools and outpools are compared in Chapter 3 to examine the longitudinal heterogeneity of the UMRS. The environmental factors correlated with the longitudinal patterns and temporal dynamics of aquatic vegetation in the UMRS are identified in Chapter 4. The effectiveness of an environmental engineering project (HREP) to promote aquatic vegetation growth in Pool 8 is examined in Chapter 5. Each chapter consists of introduction, methods, and results sections. Conclusions are drawn at the end of the report in Chapter 6.

Table 1.1. Sampling area acres, number of sites sampled, and field days per year of the transect sampling versus the stratified random sampling (SRS).

Sampling area	Acres		Number of sites sampled per year (average ± standard deviation)		Field days per year (average ± standard deviation)	
	Transect	SRS	Transect	SRS	Transect	SRS
Pool 4	3,236	80,946	1,743 ± 86	600 ± 50	29 ±4	27 ± 4
Pool 8	873	70,514	2,468 ± 215	621 ± 50	33 ± 4	24 ± 1
Pool 13	1,527	77,224	1,653 ± 148	572 ± 24	31 ± 6	26 ± 3
Pool 26[a]	669	55,245	878 ± 319	467 ± 129	9 ± 3	28 ± 5
La Grange Pool	287	76,128	325 ± 78	462 ± 55	14 ± 3	29 ± 1

[a]Includes the lower 12 miles of the Alton Pool of the Illinois River

Chapter 2: Status and Trends

The 9-foot navigation channel developed in the Upper Mississippi River during the early twentieth century altered the river's geomorphology and flow regimes (Belt 1975; Simons et al 1975; Scarpino 1985; Grubaugh and Anderson 1989), and consequently brought about major changes in the river's plant communities. Terrestrial species were extirpated on newly inundated areas and aquatic species took their place (Yeager 1949, Green 1960). Water smartweeds (*Polygonum* spp.) were the dominant plants during the first 5 years. Soon after, smartweeds were replaced by assemblages of pondweeds (*Potamogeton* spp.), coontail (*Ceratophyllum demersum* L.), water stargrass (*Heteranthera dubia* [Jacq.] MacM.), and American wildcelery (*Vallisneria americana* Michx.; Green 1960; Rogers and Theiling 1998). Since the early 1960s, American wildcelery has become the most common species in the impounded areas of Pools 4–14 (Rogers 1994; Rogers and Theiling 1998).

The 9-foot navigation channel has undoubtedly changed the ecological function of the UMR in many ways, most of which have yet to be revealed and understood. One way, for example, is an observed shift of waterfowl migration routes toward the UMR in the 1960s and 1970s concurrent with the proliferation of American wildcelery in the UMR and deterioration of this important food source elsewhere (Korschgen et al. 1988; Korschgen and Green 1988). Aerial photos collected over the past six decades reveal a steady eroding of islands in the impounded areas of Pool 8 and a subsequent retreat of SAV (Fischer and Claflin 1995). Following a basin-wide drought (1987–89), SAV in many pools of the UMR declined rapidly within a few years (Rogers 1994; Fischer and Claflin 1995). Many biologists were concerned that the UMR was following the footsteps of the Illinois River where SAV collapsed during the 1950s and has not yet recovered. When aquatic vegetation monitoring under the LTRMP was initiated in 1991, establishing a reference point and detecting trends in terms of frequency of occurrence was a top priority identified by river managers. A central question was whether the decline of SAV observed in the aftermath of the drought was continuing.

Methods

Data presented in this chapter were restricted to those collected from 1991 to 2000 using the transect sampling protocol (Rogers and Owens 1995) and those collected from 1998 to 2002 using a stratified random sampling protocol (SRS; Yin et al. 2000b).

Transect Sampling Protocol

In 1991, transects were placed in selected backwaters in a nonrandom fashion and sites were sampled at either 15 or 30m intervals along each transect (Figures 1.2–1.6). Aquatic vegetation was sampled once in spring and once in summer. Generally, spring sampling was between May 15 and June 15 and summer sampling was between July 15 and August 31. The method used to sample aquatic vegetation at each site was modified from a technique used by Jessen and Lound (1962). A 2-m diameter sampling area was located immediately in front of the bow of the sampling boat. The sampling area was divided into thirds and plants were collected in each third using a long-handled thatching rake. The rake was lowered to the bottom, twisted 180 degrees to snag vegetation, and retrieved. Submersed plant species collected on the rake were identified and recorded. After all three thirds were sampled; each species present was assigned a rating of 1, 2, or 3 on the basis of the number of retrievals. A rating of 4 was assigned to signal high abundance if the biomass filled the rake on all three retrievals. Beginning in 1997, a rating of "9" was recorded to indicate the species was observed in the sampling area but not retrieved on the rake. Previously, species observed but not retrieved were not recorded other than as occasional notes in the comment column. If a rooted floating-leaf species was present, its vegetative percent cover in the sampling area was recorded as follows: 1 = 1–25% cover, 2 = 26–50% cover, 3 = 51–75% cover, and 4 = 76–100% cover.

Stratified Random Sampling Protocol

The stratified random sampling protocol (Yin et al. 2000b) was developed to expand the spatial coverage of aquatic vegetation sampling from limited focal backwaters to the entire aquatic area where SAV could potentially exist, to randomize the location of sampling sites, and to enhance the precision of our estimates. The new sampling protocol was initiated to provide pool-wide, unbiased, and precise estimates for indices of abundance for submersed aquatic vegetation in the key pools.

Shallow aquatic areas where SAV could potentially exist were mapped using bathymetric data collected under the LTRMP. The maximum depth for sampling was 3 m in 1998, but following an analysis of the data collected, the maximum depth was reduced to 2.5 m in subsequent years. Shallow water areas were then classified into five general habitat types (strata): main channel borders, secondary channels, contiguous backwaters, isolated backwaters, and impounded areas. Allocation of sample sizes among strata was initially based on acreage and perceived habitat heterogeneity. The initial allocation was adjusted in subsequent years on the basis of power analysis (90% power for detecting 20% of annual pool-wide changes) as well as other factors including the water level drawdown experiment in Pool 8 during 2001 and 2002, outpool sampling, and funding fluctuations. Sampling locations were selected using a random number generator. Site selections among years were independent except that the 2001 sites in Pool 8 were revisited in 2002 to track changes occurring at individual sites. The revisit of 2001 sites in 2002 should not have had materially adverse effects on the estimation of stratum-wide or pool-wide means.

A site was sampled in six areas distributed in a cluster surrounding the boat: four off the corners and two off the left and right sides. Aquatic vegetation was collected from the six subsampling areas using a long-handled double-headed rake made by welding two square-headed garden rakes together. The teeth were divided and marked into five equal parts (or 20% increments). The rake was extended out 1.5 m, lowered to the sediment, and dragged back to the boat to snag vegetation. Individual species and different life forms of aquatic vegetation were recorded as either present or absent on the basis of a visual examination and their presence in a rake sample. When present, submersed species and filamentous algae were given a density rating based on their thickness on the rake teeth, whereas, rooted floating-leaf and emergent species were given a percent cover rating on the basis of a visual estimation.

Data Analysis

The presence or absence of species at each site was used to calculate the percent frequency of occurrence in each stratum and in all strata combined. The percent frequency of occurrence is an index of prevalence. For example, SAV was recorded at 89 of the 170 sites sampled in the contiguous backwater areas of Pool 13 in 1998, therefore, its percent frequency of occurrence was calculated as

$$y = \frac{a}{n} * 100 = \frac{89}{170} * 100 = 52$$

where y = percent frequency of occurrence, a = number of times a species was present, n = number of sites sampled, and, where the variance of frequency of occurrence was calculated as

$$s^2 = \frac{y*(100-y)}{n} = \frac{52*(100-52)}{170} \cong 15$$

where y = percent frequency of occurrence and n = number of sites sampled.

If the study area consisted of several substudy areas or stratum investigated separately, the percent frequency of occurrence of the study area ($\bar{y}_{pooled}$) and its variance $[s^2(\bar{y}_{pooled})]$ were estimated using the formulas for stratified random sampling design (Cochran 1977; Gutreuter 1997);

$$\bar{y}_{pooled} = \frac{\sum_{h=1}^{l} N_h y_h}{\sum_{h=1}^{l} N_h}$$ and

$$s^2(\bar{y}_{pooled}) = \left(\frac{1}{\sum_{h=1}^{l} N_h}\right)^2 \sum_{h=1}^{l} N_h \frac{N_h - n_h}{N_h} \frac{s_h^2}{n_h},$$

where y_h and s_h^2 are percent frequency of occurrence and its variance, respectively, in stratum h; N_h is the acreage of stratum h in terms of the number of sampling units; and n_h is the number of units of N_h investigated.

Pool 4 was split into upper and lower sections, divided by a line through Lake Pepin at river mile 775 because the two sections displayed distinctively different vegetation dynamics. The lower 12 miles of the Illinois River, sampled along with Pool 26, UMR, was treated as a separate pool in analysis because it represents a different river. Because the transect and SRS data differ in spatial coverage as well as by sampling method, we did not expect them to result in similar estimates. However, we hoped their trends were similar.

Results

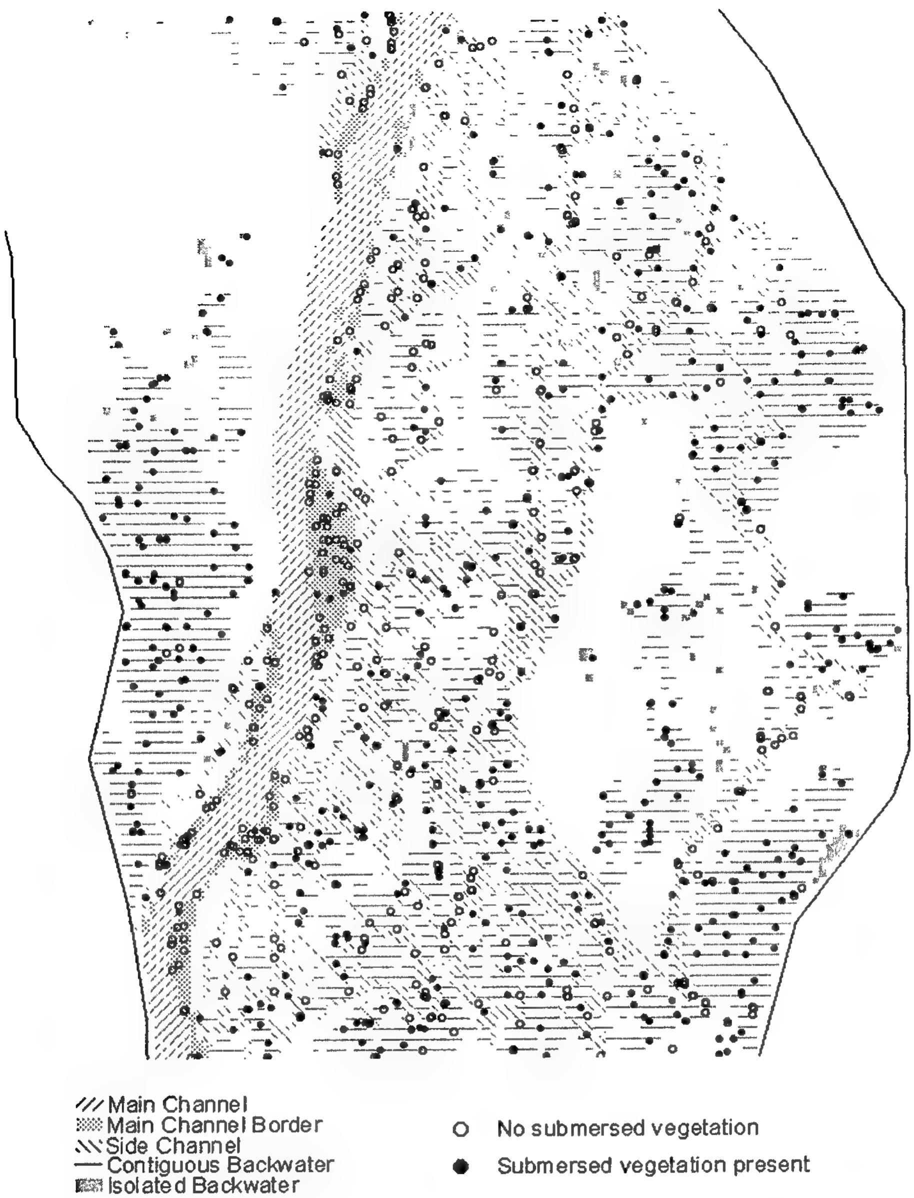
Distribution Patterns

Water clarity and current velocity are two major physical variables regulating the distribution of SAV in slow-flowing North American rivers (Chamber et al. 1991; Vis et al. 2003). In the UMR, SAV is affected by many factors, including water clarity and current velocity. The distribution is complex yet some general patterns are revealed by the LTRMP data. The UMR is a large, braided floodplain river with extensive backwaters of various degrees of connectivity to the main channel. A typical cross section of the river consists of a few hydrogeomorphic features, including the main channel where commercial navigation occurs, the main channel borders, side channels, contiguous backwaters connected to the river year-round, and isolated backwaters connected to the river only during floods. The frequency of occurrence of SAV was highest in isolated backwaters, followed by contiguous backwaters, side channels, and main channel border in decreasing order (Figure 2.1; Appendix B). Such a gradient indicates that increased connectivity to the main channel has a net negative influence on SAV. The farther away and therefore less influenced by the main channel, the better the chance for SAV to grow. Average current velocity, average water depth, and average wind fetch (distance to the nearest land mass weighted by the direction and duration of winds during a year) displayed a similar gradient (Figure 2.1).

Another hydrogeomorphic gradient exists within a navigation pool. The tailwater below the upstream dam is most similar to the natural river whereas the impounded area above the downstream dam is least similar to the natural river. The deeper and faster flow in the upper section of the pool is a major limiting factor to SAV relative to the shallower and slower flow in the mid- and lower sections (Figure 2.2). The mid- and lower sections have about the same average depth. The lower section, however, has slightly slower current (28 versus 34 cm/s) but much higher effective wind fetch (2,510 versus 1,220 m) than the midsection. The positive influence of slower current is cancelled by the negative influence of higher effective wind fetch. As a result, the two sections have about the same level of SAV presence. These within-pool patterns are consistent with historical accounts that the establishment of the locks and dams navigation system has vastly increased the extent of SAV in the UMR because of the creation of an expansive shallow impoundment area.

Across the UMR System (UMRS), SAV was widespread in lower Pool 4, Pools 5, 7, 8, and 13, and rare in Pool 26 and Alton and La Grange Pools (Table 2.1). Submersed aquatic vegetation was common to infrequent in upper Pool 4 and Pools 11 and 12. Lake Pepin, Pool 4, acted as a sink for suspended solids (Figure 2.3) improving the water clarity in the lower part of the pool (J. Houser, USGS-UMESC, unpublished data). This, in part, accounted for the difference in the amount of SAV between upper and lower Pool 4. Factors behind the system-wide distribution pattern are described in Chapter 3.

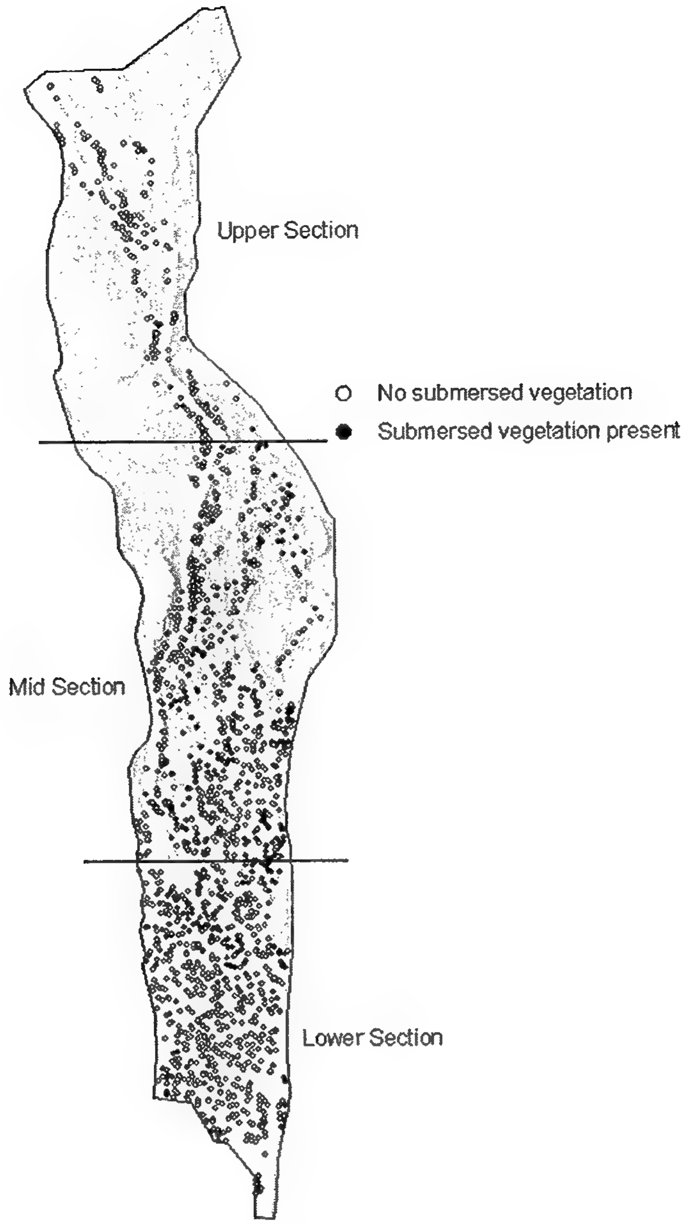
Dominant SAV species in Pools 4, 8, and 13 included American wildcelery, water stargrass, coontail, Canadian waterweed (*Elodea canadensis* Michx.), and sago pondweed (*Stukenia pectinatus* [L.] Boerner;



	Main channel		Main channel border		Side channel		Contiguous backwater		Isolated backwater	
Number of sites	ns[a]		143		316		532		12	
Percent frequency	ns[a]		11.0	(0.5)[b]	39.5	(0.5)	81.5	(0.5)	89.5	(0.5)
Average velocity (cm/sec)	105	(23)	79	(28)	38	(30)	5	(15)	1	(2)
Average depth (ft)	5.2	(1.1)	2.1	(1.1)	1.6	(1.1)	1.0	(0.7)	0.4	(0.4)
Average distance to nearest land mass (m)	600	(45)	535	(115)	245	(370)	385	(435)	25	(30)

[a]Submersed aquatic vegetation does not survive in the main channel therefore it was not sampled (ns)
[b]Standard deviation

Figure 2.1. Presence of submersed aquatic vegetation in a section of Pool 8, Upper Mississippi River, on the basis of 1998 to 2002 data pooled together. The map and associated statistics are intended to display the lateral gradient of distribution in relation to water depth (April 15–June 15), flow velocity (hydrologic model simulation under 90,000 cfs discharge at the La Crosse Gage station, unpublished data from the U.S. Army Corps of Engineers), average, and distance to nearest land mass summarized by four habitat classifications. The map focuses on a small section of the pool to reduce to help clarify the within-pool longitudinal pattern (refer to Figure 2.2).



	Lower Pool 8		Mid Pool 8		Upper Pool 8	
Number of sites	1,066		1,405		603	
Percent frequency	37.5	(0.5)[a]	40.5	(0.5)	13.0	(0.5)
Average velocity (cm/sec)	28	(11)	34	(25)	54	(34)
Average depth (m)	1.5	(0.6)	1.5	(0.9)	2.7	(1.4)
Average distance to nearest land mass (m)	2,510	(730)	1220	(960)	250	(170)

[a]Standard deviation

Figure 2.2. Presence of submersed aquatic vegetation in Pool 8, Upper Mississippi River, on the basis of 1998–2002 data pooled together. The map and associated statistics are intended to display the within-pool longitudinal pattern of submersed aquatic vegetation distribution in relation to flow velocity (hydrologic model simulation under 90,000 cfs discharge at the La Crosse Gage station, unpublished data from the U.S. Army Corps of Engineers), average water depth during April 15–June 15, and distance to nearest land mass summarized by three sections. Contiguous and isolated backwater strata were excluded from the display to reduce compounding by the latter gradient.

Table 2.1. Percent frequency of occurrence for aquatic vegetation collected during stratified random sampling in upper and lower Pool 4, Pools 5, 7, 8, 11, 12, 13, and 26 of the Upper Mississippi River and Alton and La Grange Pools of the Illinois River, Long Term Resource Monitoring Program from 1998 to 2002 (upper and lower Pool 4 and Pools 5, 7, 11, and 12 do not include the isolated backwater stratum).

	1998			1999			2000			2001			2002		
Pool	Frq[a]	Std[b]	n[c]	Frq	Std	n	Frq	Std	n	Frq	Std	n	Frq	Std	n
Submersed vegetation															
Upper Pool 4[d]	21.8	3.0	187	18.5	2.7	213	13.8	2.2	245	7.0	1.6	245	9.7	1.9	245
Lower Pool 4[d]	49.1	3.0	288	48.9	2.9	302	55.3	2.7	354	57.1	2.7	351	50.9	2.7	355
Pool 5	ns[e]			ns			ns			ns			31.6	2.3	404
Pool 7	ns			ns			ns			ns			57.4	2.5	392
Pool 8	49.3	2.2	516	58.1	2.0	595	47.7	2.0	649	47.5	1.9	670	53.4	2.0	644
Pool 11	ns			ns			ns			16.3	1.5	564	ns		
Pool 12	ns			ns			ns			ns			15.2	1.8	404
Pool 13	43.2	2.2	531	41.9	2.1	550	43.0	2.1	578	41.7	2.0	606	43.0	2.1	579
Pool 26	0.5	0.4	312	0.1	0.1	437	0.2	0.3	262	0.0	0.0	279	0.2	0.3	215
Lower Alton Pool	14.1	2.4	207	1.4	0.8	210	12.4	2.8	135	5.4	2.0	134	5.2	2.1	114
Upper Alton Pool	ns			ns			ns			ns			0.0	0.0	408
La Grange Pool	0.0	0.0	463	0.0	0.0	537	0.0	0.0	368	0.0	0.0	357	0.0	0.0	369
Rooted Floating-Leaf Vegetation															
Upper Pool 4	1.1	0.8	187	1.6	0.9	213	1.3	0.7	245	0.8	0.6	245	1.6	0.8	245
Lower Pool 4	24.9	2.6	288	17.9	2.2	302	17.1	2.0	354	13.8	1.8	351	17.4	2.0	355
Pool 5	ns			ns			ns			ns			15.1	1.8	404
Pool 7	ns			ns			ns			ns			17.2	1.9	392
Pool 8	18.0	1.7	516	19.0	1.6	595	18.9	1.5	649	18.1	1.5	670	20.7	1.6	644
Pool 11	ns			ns			ns			7.5	1.0	564	ns		
Pool 12	ns			ns			ns			ns			13.5	1.7	404
Pool 13	18.2	1.7	531	20.4	1.7	550	22.0	1.7	578	23.7	1.7	606	25.0	1.8	579
Pool 26	1.2	0.6	312	1.1	0.5	437	2.7	1.0	262	0.8	0.5	279	2.7	1.1	215
Lower Alton Pool	10.9	2.2	207	2.1	1.0	210	6.2	2.1	135	9.8	2.6	134	6.1	2.2	114
Upper Alton Pool	ns			ns			ns			ns			0.0	0.0	408
La Grange Pool	0.3	0.3	463	0.5	0.3	537	6.0	1.2	368	0.3	0.3	357	2.2	0.8	369
Emergent Vegetation															
Upper Pool 4	2.3	1.1	187	4.7	1.5	213	3.1	1.1	245	3.7	1.2	245	3.5	1.2	245
Lower Pool 4	14.8	2.1	288	10.9	1.8	302	11.4	1.7	354	11.9	1.7	351	12.8	1.8	355
Pool 5	ns			ns			ns			ns			4.1	1.0	404
Pool 7	ns			ns			ns			ns			16.0	1.9	392
Pool 8	11.2	1.4	516	15.0	1.5	595	11.5	1.3	649	9.9	1.2	670	16.4	1.5	644
Pool 11	ns			ns			ns					564	ns		
Pool 12	ns			ns			ns			ns			7.3	1.3	404
Pool 13	3.4	0.8	531	4.7	0.9	550	4.6	0.9	578	5.7	0.9	606	5.0	0.9	579
Pool 26	4.6	1.2	312	7.3	1.3	437	7.4	1.6	262	1.6	0.8	279	10.2	2.1	215
Lower Alton Pool	4.2	1.4	207	0.0	0.0	210	3.5	1.6	135	15.6	3.2	134	13.9	3.3	114
Upper Alton Pool	ns			ns			ns			ns			4.6	1.0	408
La Grange Pool	2.6	0.7	463	2.8	0.7	537	1.3	0.6	368	0.9	0.5	357	2.6	0.8	369

[a]Percent frequency of occurrence
[b]Standard error
[c]Number of sites
[d]For analysis, Pool 4 was divided into upper (above river mile 775) and lower (below river mile 775) sections
[e]Not sampled

Appendixes C and D). American wildcelery and water stargrass were most prominent in the impounded areas where current velocity is moderate, whereas coontail, Canadian waterweed, and sago pondweed were most prominent in isolated and contiguous backwater areas with little or no current (Figure 2.4). Sago pondweed was consistently recorded in the isolated backwaters of lower Alton Pool, whereas Eurasian watermilfoil (*Myriophyllum spicatum* L.) dominated the floodplain lakes of La Grange Pool.

Temporal Dynamics

Because transect data were collected from nonrandomly selected backwaters, pool-wide estimators from pooling of the backwaters were not anticipated to match pool-wide estimators from pooling of randomly selected SRS sites. The transect sampling data revealed that the frequency of occurrence of SAV varied among the years as well as between spring and summer sampling windows. In upper Pool 4 (Figure 2.5), summer estimates were consistently lower than the spring estimates. Early senescence of sago pondweed, the dominant species in upper Pool 4, was a possible cause. The SRS data collected between spring and summer transect sampling windows followed the trend of the spring data in the overlapping years. In lower Pool 4 (Figure 2.6), spring and summer data showed similar trends. The SRS data displayed the same pattern as the transect data between 1998 and 2000. In Pool 8, SRS data also agreed well with transect data on the trend of change from 1998 to 2000 (Figure 2.7). The difference between the two trend lines from 2000 to 2001 was likely related to a planned water level reduction in summer 2001 that dewatered a much greater proportion of the transect sampling sites than the SRS sites. Pool 13 displayed greater fluctuations between spring and summer data, especially in 1991 and 1993. The distinct differences between spring and summer in 1991 and 1993 reflect real changes most likely the results of excessive water turbidity in summer 1991 and record flooding in summer 1993, respectively. However, the discrepancy between spring and summer in 2000 was caused by omission (because of time

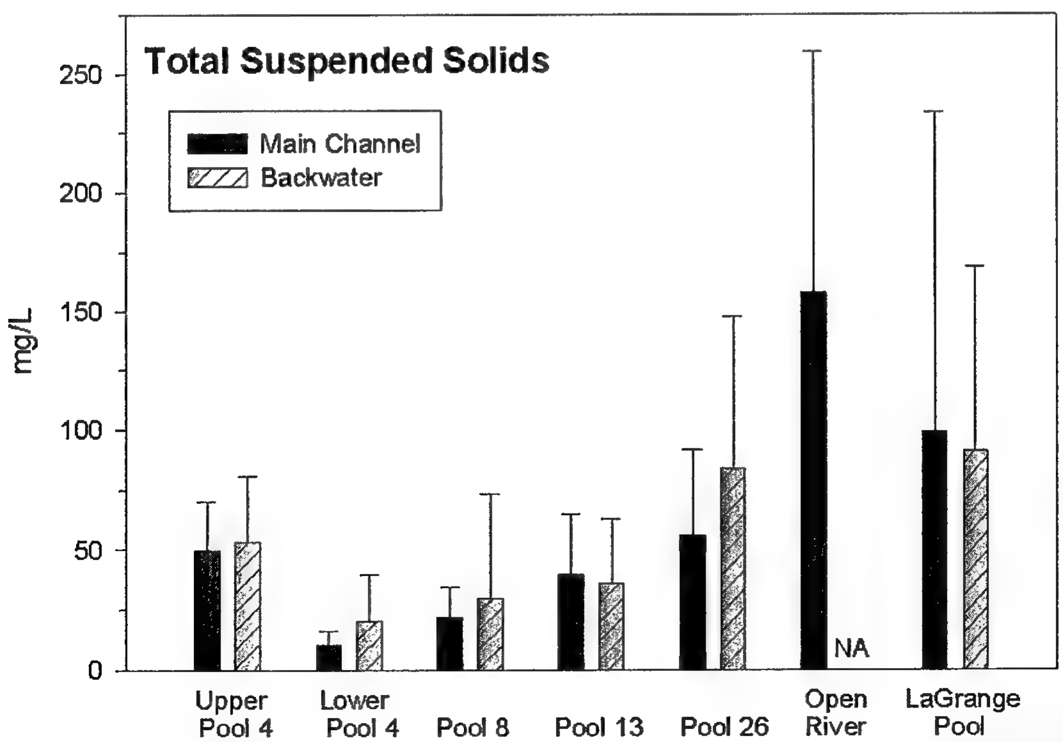


Figure 2.3. Mean total suspended solids in main channel and backwater strata in Long Term Resource Monitoring Program key pools during summer stratified sampling from 1993 through 2001. Error bars represent one standard deviation. Courtesy of Rob Burdis, Minnesora Department of Natural Resources, Long Term Resource Monitoring Program, Lake City Field Station.

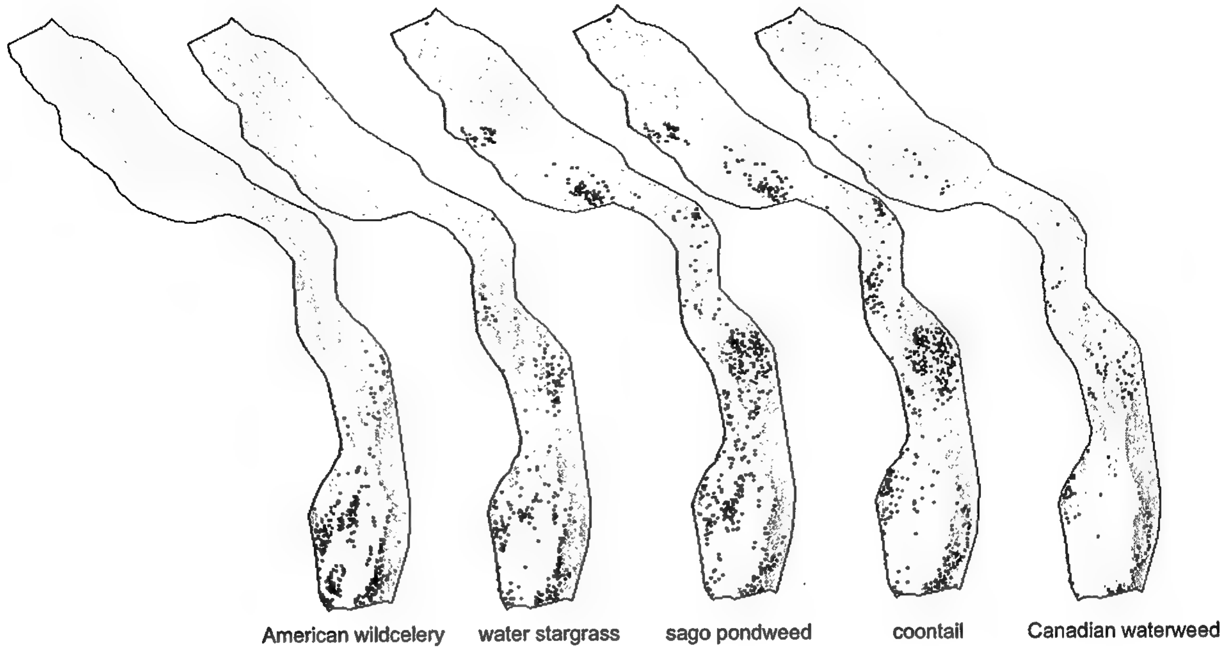


Figure 2.4. Presence of selected submersed aquatic species in Pool 13, Upper Mississippi River, from 1998 to 2002.

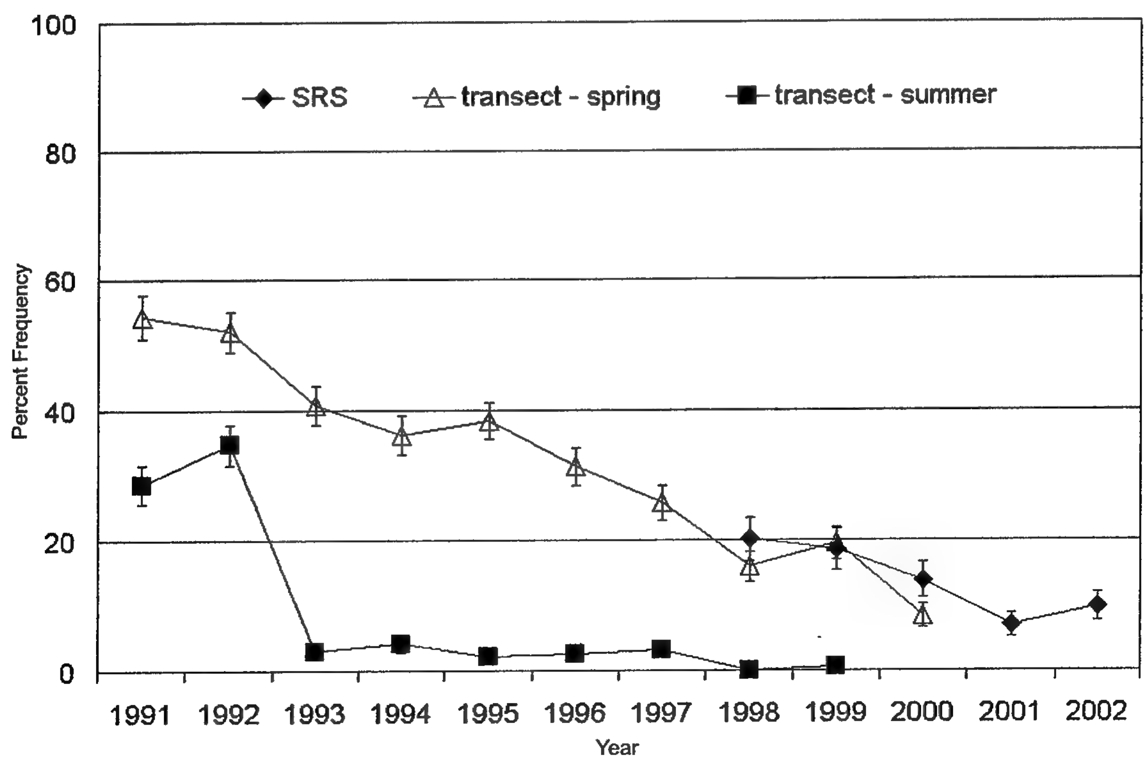


Figure 2.5. Percent frequency of submersed aquatic species from different sampling efforts by year in upper Pool 4 (above river mile 775), Upper Mississippi River. Upper Pool 4 was not sampled in spring 2000 because of time constraints.

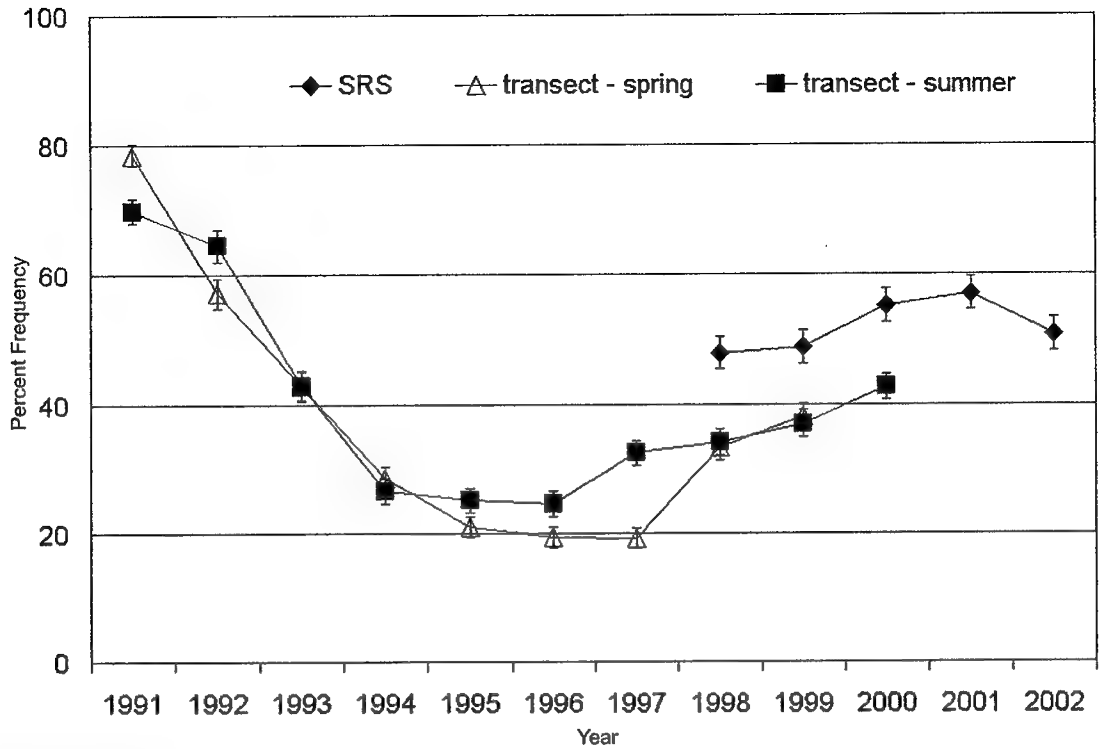


Figure 2.6. Percent frequency of submersed aquatic species from different sampling efforts by year in lower Pool 4 (below river mile 775), Upper Mississippi River. Lower Pool 4 was not sampled in spring 2000 because of time constraints.

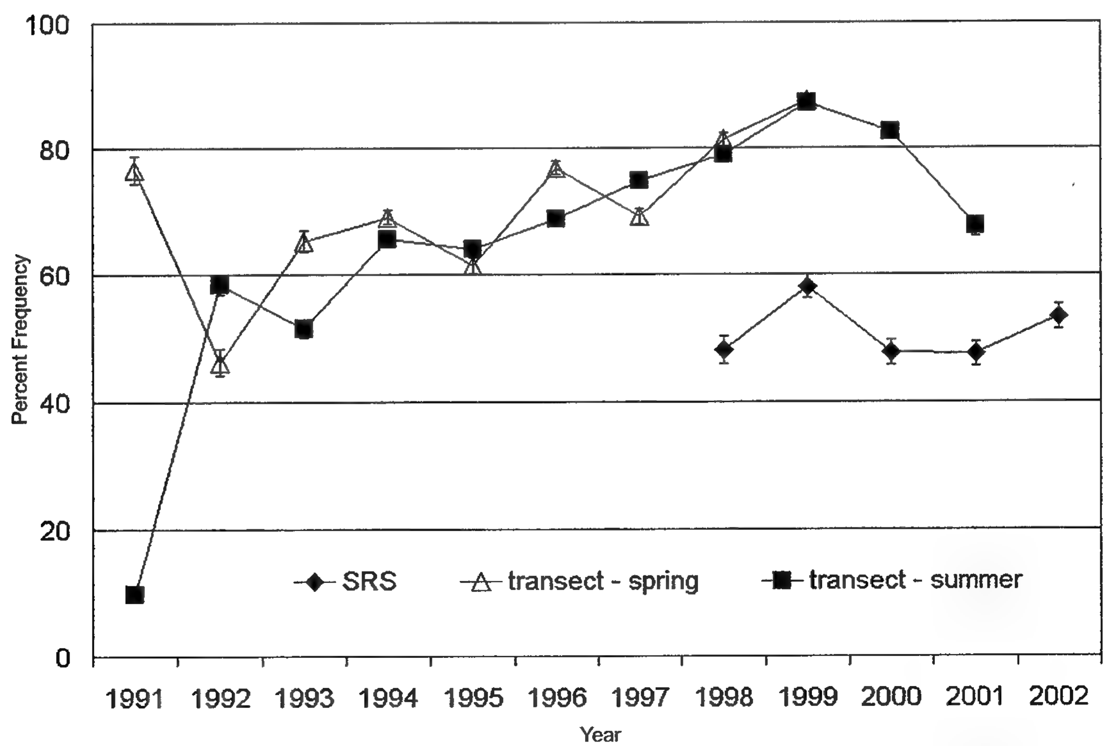


Figure 2.7. Percent frequency of submersed aquatic species from different sampling efforts by year in Pool 8, Upper Mississippi River.

constraints) of two heavily vegetated backwater areas during summer sampling (Appendix A). Had the omission not occurred, the transect and SRS data both would indicate that SAV growth in Pool 13 remained steady from 1998 to 2000 (Figure 2.8). No transects were established in Pool 26 because of a lack of sizable aquatic vegetation beds (Figure 1.5). Pool-wide SRS from 1998 to 2002 confirmed that SAV in Pool 26 is extremely rare (Figure 2.9). In lower Alton Pool, where SAV was found, the transect and SRS data clearly showed similar trends from 1998 to 2000 (Figure 2.9). In La Grange Pool, one transect area was established in the main stem of the Illinois River (Grape Island, Figure 1.6) where a small amount of sago pondweed was found in 1992, 1993, 1994, and 1999. No SAV was found in a poolwide SRS survey from 1998 to 2002. However, SAV was found in floodplain lakes not connected to the Illinois River (Figure 2.10).

The above analyses established legitimacy for merging the transect trend with the SRS trend to form a continuous trend from 1991 to 2002. We found the trends varied between the river reaches (Figures 2.5–2.10). In upper Pool 4, SAV declined steadily from 1991 to 2002. The SAV in lower Pool 4 declined steadily from 1991 to 1996, followed by a moderate recovery thereafter. The SAV in Pool 8 experienced a major setback in summer 1991 after the spring transect sampling and recovered slowly but steadily thereafter until 1999 when SAV growth peaked and exceeded the spring 1991 level (Figure 2.6). As of 2002, SAV in Pool 8 was near the peak recorded in 1999. The SAV in Pool 13 experienced summer setbacks in 1991 and in 1993. However, an immediate and complete recovery followed each setback. The patterns indicate a high degree of resilience to brief setbacks and high stability of SAV growth in Pool 13 during the period of record. The SRS data collected from 1998 to 2002 in Pool 26 and La Grange Pool revealed the extreme scarcity of SAV growth in the two pools. No transects were established in the rivers and their contiguous backwaters indicate the same situation was true in 1991–1997. The lower Alton Pool supported SAV growth in most years since 1991, especially during spring time (Figure 2.9).

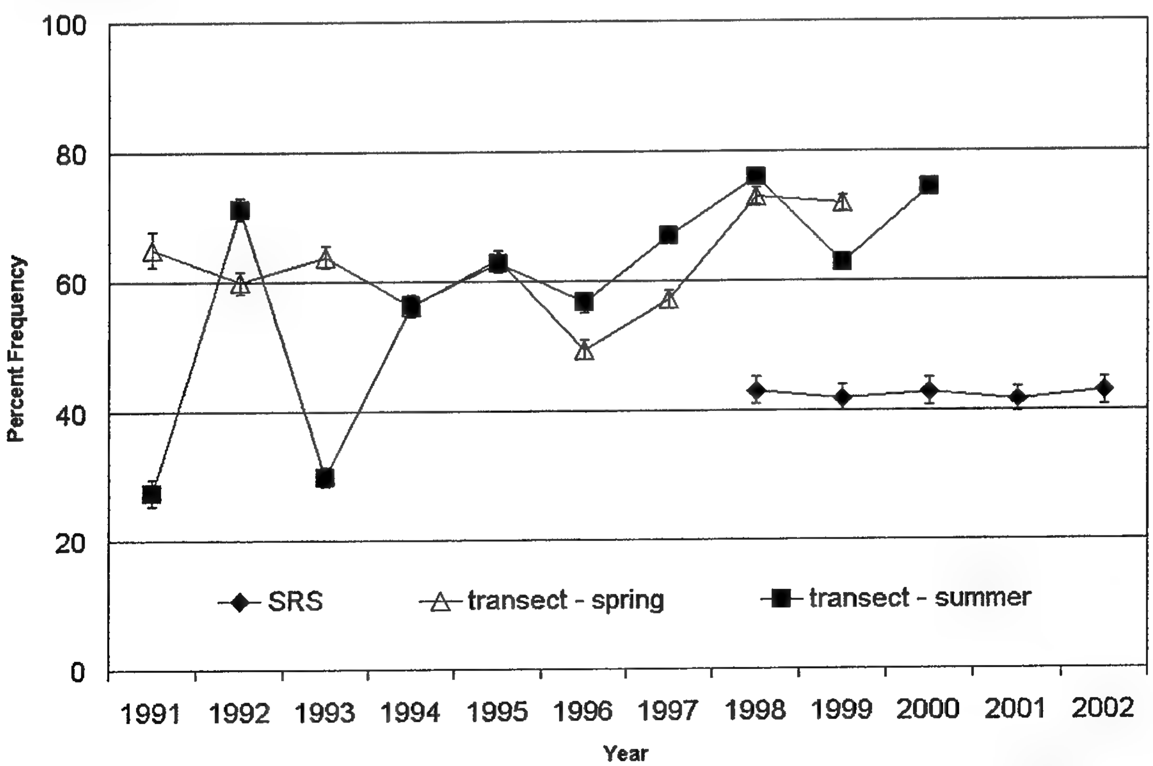


Figure 2.8. Percent frequency of submersed aquatic species from different sampling efforts by year in Pool 13, Upper Mississippi River. Data from spring 2000 was not included in the analysis because two backwaters were not sampled because of time constraints.

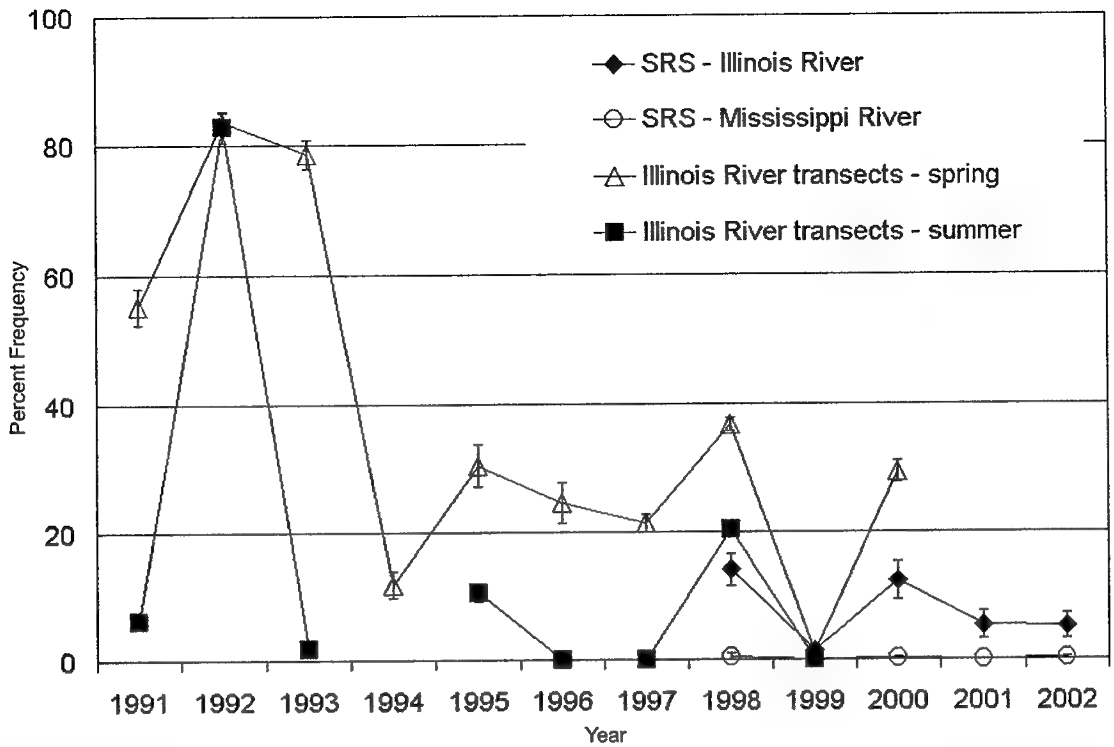


Figure 2.9. Percent frequency of submersed aquatic species from different sampling efforts by year in Pool 26, Upper Mississippi River, and the lower 12 miles of Alton Pool, Illinois River. Transect sites were from backwaters of the Illinois River. Transects were not sampled in the summer of 1994 because they were dewatered to promote annual vegetation growth for waterfowl.

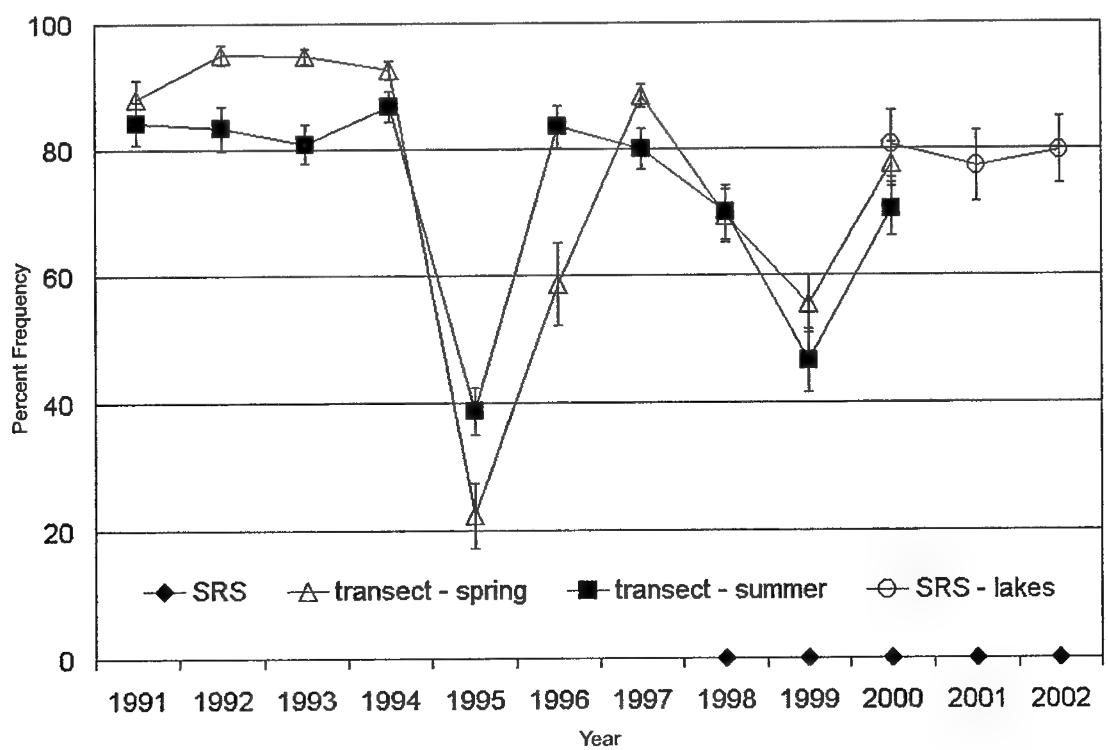


Figure 2.10. Percent frequency of submersed aquatic species from different sampling efforts by year in La Grange Pool, Illinois River. Transects were in floodplain lakes not influenced by the Illinois River. These areas correspond to the lakes stratum used in stratified random sampling. The lake stratum was not included in the pool-wide estimate for La Grange Pool.

Chapter 3: Outpool Sampling

The general design of the LTRMP monitoring operates under the assumption that the six key pools represent a wide spectrum of UMRS habitats. We tested the validity of the assumption with regard to aquatic vegetation. Field data were collected using the SRS protocol in Pool 11 in 2001 and in Pools 5, 7, 12, and upper Alton Pool in 2002. Our approach examined the similarity of species composition and of community structure between the key pools and the outpools. For species composition, we wanted to know how many species recorded in the outpools were not recorded in the key pools and, conversely, how many species recorded in the key pools were not recorded in the outpools. If the key pools represented a wide spectrum of habitats within the UMRS, the number of species unique to the out pools would be small. In terms of community structure, we wanted to know how similar or dissimilar the outpools were to the key pools.

Methods

We conducted a detrended correspondence analysis of the species–sample matrix with down-weighting of infrequent species using the CANOCO 4.5 software (ter Braak and Smilauer 2002). The input dataset is a species–sample matrix. Each sample represents one pool in one year, consisting of the percent frequency of occurrence values of individual species (columns). All aquatic vegetation species, including submersed, emergent, and rooted floating-leaf species were included in the matrix. All SRS data collected from 1998 to 2002 were used in the analysis.

Results

Fifty-six species were found in the five outpools, 51 of which were found in the key pools. The five species not found in the key pools included an unidentified species of horsetail (*Equisetum* spp.), dotted smartweed (*Polygonum punctatum* Elliot), and an unidentified watercrowfoot (*Ranunculus* spp.) found in Pool 7, and tufted lovegrass (*Eragrostis pectinacea* [Michx] Nees x Steud.) and graybark grape (*Vitis cinerea* [Engelm.] Millard) found in upper Alton Pool. In comparison, 121 species were recorded in the key pools, 70 of which were not found in the five outpools. The number of new species found in the outpool sampling was small and the new species were common components of the more xeric terrestrial habitats.

The first and second ordination axes accounted for 34% of the variance of the sample–species matrix, which indicated the patterns revealed on the two-dimensional ordination plane were not particularly strong. This is not surprising given our understanding of the biological and ecological complexity of the UMRS and that all species rather than a selected few were included in the analysis. The ordination chart revealed that all the outpool samples fell within the space formed by the key pools (Figure 3.1). Pools 5 and 7 were similar to lower Pool 4 and Pool 8 and they formed a tight cluster. Pools 11 and 12 fell between Pool 13 and upper Pool 4 and were not as tightly clustered. Upper Alton Pool of the Illinois River falls into the domain of Pool 26 of the Mississippi River and La Grange Pool of the Illinois River. Upper Pool 4 appeared to be out-of-place in the aquatic vegetation species ordination plane and the pattern indicates upper Pool 4 was more similar to Pool 13 than to lower Pool 4 and Pool 8 (Figure 3.2).

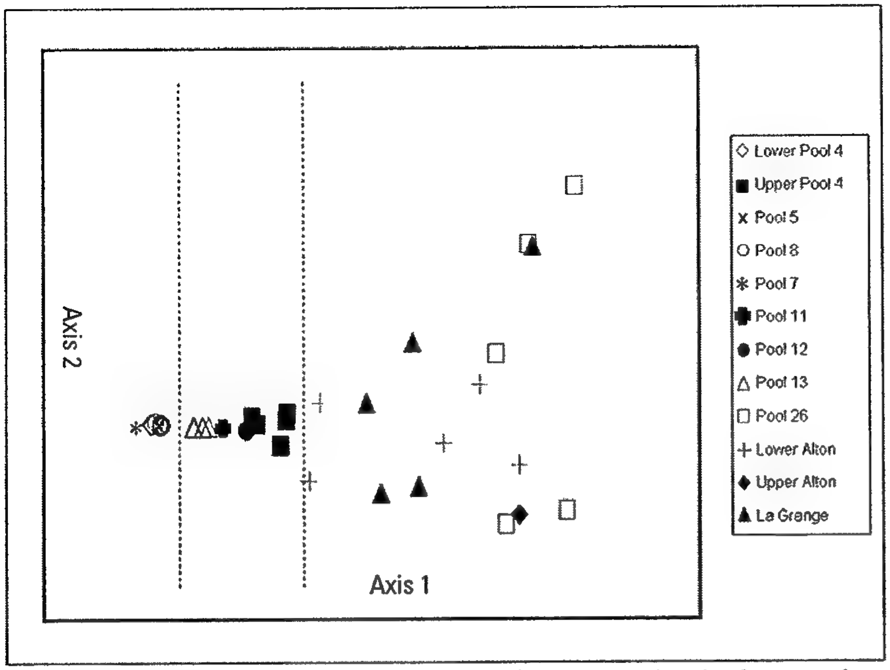


Figure 3.1. Detrended correspondence analysis (ordination) of study areas based on frequency of occurrence of all aquatic species from 1998 to 2002. For analysis, Pool 4 was divided into upper (above river mile 775) and lower (below river mile 775) sections.

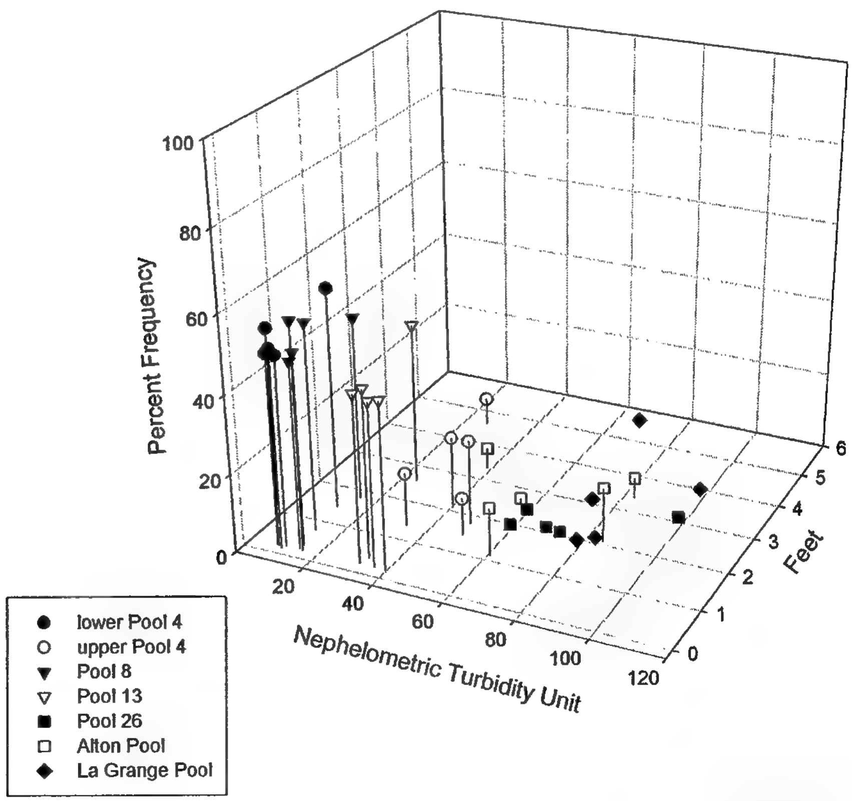


Figure 3.2. Correlation between percent frequency of submersed aquatic vegetation and two environmental factors, mean water turbidity (calculated from measurements taken between May 1 and August 31 from one Long Term Resource Monitoring Program fixed site near the main channel at the upper end of each pool or section) and water level fluctuations (standard deviation of daily water levels), by pool ($r^2 = 0.82$). For analysis, Pool 4 was divided into upper (above river mile 775) and lower (below river mile 775) sections.

Chapter 4: Environmental Factors

Many factors could limit SAV in a river system. For the UMRS, small-scale field studies and laboratory experiments have confirmed light and nutrients as limiting factors (Kimber et al 1995; Rogers et al. 1995; Korschgen et al. 1997). Sediment related factors eradicated SAV from the Illinois River during the 1950s (Mills et al. 1966; Bellrose et al. 1979; Sparks et al. 1990). A general belief among the biologists on the UMR is that the system-wide pattern of SAV is dictated by water turbidity (i.e., the general lack of SAV in the lower reaches is because of excessively high water turbidity; Rogers and Theiling 1998). Whereas this hypothesis was supported by anecdotal evidence, it had yet to be tested with scientific data. In this chapter we explored whether or not high turbidity and water level fluctuation were related to the lack of SAV (Barko et al. 1986; Rorslett and Johansen 1996; Blanch et al. 1998; Bini et al. 1999; Doyle and Smart 2001).

Methods

An analysis of variance was conducted using the general linear model procedure of SAS (SAS Institute Inc. 1999). The dependant variable was the annual frequency of occurrence of SAV from 1998 to 2002 computed using the SRS data. The explanatory variables were the mean water turbidity and the standard deviation of daily water levels, May 1–August 31. Mean water turbidity was computed using the fixed-site monitoring data collected biweekly by the LTRMP water quality component (Soballe and Fischer 2004). Among the many fixed sites monitored by the LTRMP, we selected one site in the main channel at the upper end of each pool or section so water turbidity measurements represented inflow conditions (Table 4.1). Water level fluctuation was quantified using the standard deviation of the daily water levels at the closest gage station operated by the U.S. Army Corps of Engineers (Table 4.1).

Results

Our analysis revealed a negative correlation between the two physical factors, water turbidity and water level fluctuation, and the percent frequency of SAV (Table 4.2; Figure 3.2). Together, the two variables accounted for 82% of the variance in SAV frequencies ($r^2 = 0.82$). Turbidity was a much stronger predictor of SAV than water level fluctuation (Type III sum of square 4,464 versus 1,392 in Table 4.2).

We examined whether the correlations between SAV and turbidity and between SAV and water level fluctuation were artifacts of a strong longitudinal gradient along the UMRS from north to south for all three variables (SAV [decreasing], water turbidity [increasing], and water level fluctuation [increasing]). If our hypothesis was true, turbidity and water level fluctuation would become obsolete predictors of SAV in the presence of river mile as a predictor in the model. A test revealed that our suspicion was not warranted. Turbidity and water level fluctuation continued to be strong predictors despite the presence of river mile. Thus, river mile was a nonsignificant predictor in the presence of turbidity and water level fluctuation in the model (Table 4.3).

Our analyses also revealed that the turbidity and water-level fluctuation were good predictors of the longitudinal variation but poor predictors of yearly variation of SAV. Whereas pools with less turbid and less fluctuating water had higher frequencies of SAV presence than pools with more turbid and more fluctuating pools, years of less turbid and less fluctuating water did not consistently have higher frequencies of SAV presence than years of more turbid and more fluctuating water. Additional analyses revealed that water depth should be considered together with turbidity and water level fluctuation to explain the yearly variations. Additional publications are planned to describe this evaluation in greater detail.

Table 4.1. Long Term Resource Monitoring Program water quality sites and U.S. Army Corps of Engineers gage station by pool.

Pool	River	Water quality site	Gage station
Upper Pool 4	Mississippi	M796.9N	Lock and Dam 3 tailwater elevation, Welch, Minnesota
Lower Pool 4	Mississippi	M764.3A	Lock and Dam 4 pool elevation, Alma, Wisconsin
Pool 8	Mississippi	M701.1B	Lock and Dam 8 pool elevation, Genoa, Wisconsin
Pool 13	Mississippi	M556.4A	Lock and Dam 13 pool elevation, River Mile 522.4
Pool 26	Mississippi	M241.4K	Melvin Price Lock and Dam pool elevation, Alton, Illinois
Alton Pool	Illinois	I007.0W	Alton - Grafton
La Grange Pool	Illinois	I157.8D	La Grange Lock and Dam pool elevation, River Mile 80.2

Table 4.2. Results from an analysis of variance to determine the effects of turbidity and water level elevation on the percent frequency of submersed aquatic vegetation ($r^2 = 0.82$), Long Term Resource Monitoring Program, Upper Mississippi River System.

Source	DF	Sum of squares	Mean square	F-value	P-value
Model	2	14,205	7,102	75.15	<0.0001
		Type I			
Water turbidity	1	12,812	12,812	135.57	<0.0001
Water level fluctuation	1	1,392	1,392	14.73	0.0006
		Type III			
Water turbidity	1	4,464	4,464	47.23	<0.0001
Water level fluctuation	1	1,392	1,392	14.73	0.0006
Error	32	3,024	95		
Corrected total	34	17,229			

Table 4.3. Results from an analysis of variance to determine the effects of turbidity, water level elevation, and river mile on the percent frequency of submersed aquatic vegetation ($r^2 = 0.84$), Long Term Resource Monitoring Program, Upper Mississippi River System.

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	3	9,611	3,203	38.90	<0.0001
		Type I			
River mile	1	3,546	3,546	43.06	<0.0001
Water turbidity	1	5,080	5,080	61.69	<0.0001
Water level fluctuation	1	984	984	11.96	0.0024
		Type III			
River mile	1	62	62	0.76	
Water turbidity	1	2,068	2,068	25.12	<0.0001
Water level fluctuation	1	984	984	11.96	0.0024
Error	21	1,729	82		
Corrected total	24	11,341			

Chapter 5: Habitat Rehabilitation and Enhancement Project

Habitat Rehabilitation and Enhancement Projects (HREP) and the LTRMP are two key elements of the Environmental Management Program (U.S. Army Corps of Engineers 1997). As an HREP, the U.S. Army Corps of Engineers constructed two rock sills and seven sand islands topped with silt and clay soils in the impounded area of Pool 8 near Stoddard, Wisconsin. The construction of the Stoddard HREP started in October 1997 and was completed in August 1998. Approximately 600 acres of aquatic area was enclosed and flow velocity and wave action were reduced.

Major goals of the project were to (1) improve habitat conditions for backwater fish species with an emphasis on habitat for Centrarchids, (2) increase high quality waterfowl habitat to 600 acres and then maintain, and (3) create habitat for migratory birds other than waterfowl (Neotropical migrants, marsh and water birds, and shorebirds). Additional goals include increasing turtle nesting habitat; restoring habitat for mammals (primarily beaver, mink, and muskrats), reptiles, and amphibians; and improving conditions for the reestablishment of roosting habitat for species such as bald eagles, peregrine falcons, and other raptors (USACE 1996). A matrix of physical and biotic criteria were set *a priori*, including levels of dissolved oxygen, current velocity, water depth, cover of aquatic vegetation, etc. Although aerial photos collected before and after the construction have often been used to demonstrate the unmistakable success of aquatic vegetation growth, species-level information was not included. Our objective was to document changes in species composition and abundance in the HREP area.

Methods

We delineated the HREP enclosed area and an adjacent area to the west and treated them as a treatment-control pair (Figure 5.1). Because the two areas did not have identical initial conditions (in 1997), we were looking for distinct differences between them in aquatic vegetation changes from 1998 to 2002. An index of abundance for individual species and for different life forms (submersed, emergent, and rooted floating-leaf vegetation) was computed using the SRS data. Because of small sampling size in the treatment area (14–19 sites yearly), quantification of aquatic vegetation was based on the abundance index (Yin et al. 2000a), which is more sensitive to changes than the frequency of occurrence index. The abundance index incorporates different formulas depending on the life form of the plants. For emergent and rooted floating-leaf species, the abundance index corresponds to the visually estimated percent cover categories (0%, 20%, 40%, 60%, 80%, 100%). For SAV, the abundance index is computed using the following formula (Yin e al. 2000a):

$$A = \frac{\log 2\left(1 + \sum_{i=1}^{6} V_i\right) + 3^{\left[\log 2\left(1 + \frac{\sum_{i=1}^{6}(R_i - V_i)}{6}\right)\right]} - 1}{14.6260} \times 100$$

where V_i is the presence/absence (1,0) and R_i is the plant density ranking (0,1,2,3,4,5) data for the i^{th} subsampling areas at the site (i=1,2,3,4,5,6). Data are treated before computation so that V_i=1 if R_i>= 1 and, vice versa, R_i>= 1 if V_i=1.

Results

At the time of HREP construction in summer 1998, the treatment area had a less diverse and less abundant aquatic vegetation community compared with the control area. The treatment area contained 6 submersed species and no emergent and rooted floating-leaf species, as compared to 11 submersed, 1 emergent, and 2 rooted floating-leaf species contained in the control area (Tables 5.1 and 5.2). In the following 4 years, eight new species (four submersed, two rooted floating-leaf, and two emergent) were collected. The abundance index of SAV increased from 7.4 to 24.8; and the cover of rooted floating-leaf vegetation increased from nonexistant to 24.8%; and cover of emergent vegetation increased from nonexistant to 5.2% (Table 5.2; Figure 5.2). In contrast, the control area displayed a general decline in submersed and rooted floating-leaf aquatic vegetation and

no statistically significant increase in emergent vegetation during the same period. Not all species were recorded in every year in the control area, but the pattern of hits and misses is the result of random chance rather than new colonization (Table 5.1).

As of summer 2002, the fourth growing season after completion of construction, coontail, Canadian waterweed, and American lotus (*Nelumbo lutea* [Willd.] Pers) maintained a strong momentum of growth in the treatment area. In contrast, American wildcelery increased between 1999 and 2000 and its distribution and abundance leveled off thereafter (Figure 5.3). The distributional pattern is that SAV dominates the water column in deeper (> 0.5 m) regions and American lotus dominates the surface of shallower (< 0.5 m) regions. Plant responses in the Stoddard HREP area are still unfolding and much more will be learned in the coming years. Knowledge accumulated here can be used in HREP design to promote specific vegetation assemblages.

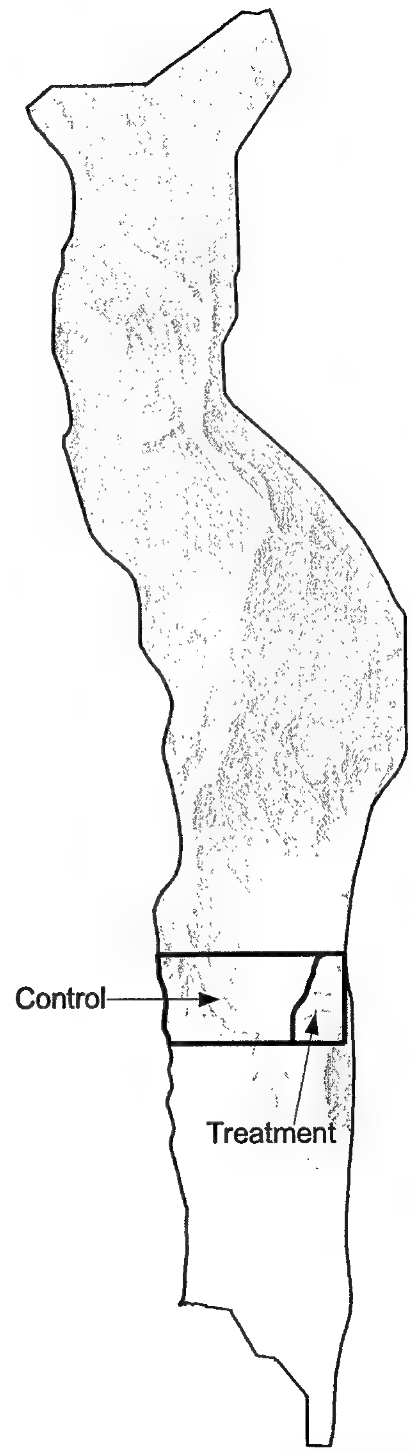


Figure 5.1. Treatment and control area in the impounded area near Stoddard, Wisconsin, in Pool 8, Upper Mississippi River.

Table 5.1. Abundance index by species outside the Stoddard Bay Habitat Rehabilitation and Enhancement Project area of Pool 8, Upper Mississippi River System.

Scientific name	Common name	1998 (n = 96)	1999 (n = 115)	2000 (n = 132)	2001 (n = 108)	2002 (n = 108)
All submersed species		**11.2 ± 1.0**	**8.1 ± 0.6**	**3.9 ± 0.4**	**3.7 ± 0.4**	**6.6 ± 0.6**
Ceratophyllum demersum	coontail	1.8 ± 0.4	2.3 ± 0.4	0.9 ± 0.2	0.9 ± 0.2	2.0 ± 0.4
Chara spp.	muskgrass	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Elodea canadensis	Canadian waterweed	6.9 ± 0.9	2.9 ± 0.4	0.8 ± 0.2	1.6 ± 0.3	3.9 ± 0.5
Heteranthera dubia	water stargrass	3.7 ± 0.5	3.2 ± 0.4	2.6 ± 0.3	2.1 ± 0.3	4.5 ± 0.5
Myriophyllum spicatum	Eurasian watermilfoil	1.1 ± 0.2	1.4 ± 0.3	0.3 ± 0.1	0.3 ± 0.1	1.9 ± 0.3
Najas flexilis	nodding waternymph	0.1 ± 0.1	1.2 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Potamogeton crispus	curly pondweed	0.6 ± 0.2	0.8 ± 0.2	0.0 ± 0.0	0.7 ± 0.2	0.4 ± 0.2
Potamogeton foliosus/pusillus	leafy/small pondweed	0.8 ± 0.2	1.4 ± 0.3	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1
Potamogeton nodosus	longleaf pondweed	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1
Potamogeton zosteriformis	flatstem pondweed	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Stuckenia pectinatus	sago pondweed	2.4 ± 0.4	1.4 ± 0.2	0.7 ± 0.2	1.3 ± 0.3	1.2 ± 0.3
Vallisneria americana	American wildcelery	2.6 ± 0.5	1.5 ± 0.3	1.2 ± 0.3	1.0 ± 0.2	2.0 ± 0.3
Zannichellia palustris	horned pondweed	0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
All rooted floating-leaf species		**12.0 ± 2.1**	**10.1 ± 1.9**	**3.8 ± 1.1**	**1.4 ± 0.6**	**3.4 ± 0.6**
Nelumbo lutea	American lotus	10.5 ± 1.9	6.2 ± 1.6	3.8 ± 1.1	1.4 ± 0.6	3.1 ± 0.6
Nymphaea odorata	white waterlily	1.9 ± 0.8	3.9 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2
All emergent species		**0.4 ± 0.2**	**5.2 ± 1.4**	**0.1 ± 0.1**	**0.0 ± 0.0**	**1.9 ± 0.6**
Eleocharis spp.	spikerush	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Phalaris arundinacea	reed canarygrass	0.0 ± 0.0	0.8 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Sagittaria latifolia	broadleaf arrowhead	0.0 ± 0.0	4.6 ± 1.3	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.6
Sagittaria rigida	stiff arrowhead	0.4 ± 0.2	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Schoenoplectus fluviatilis	river bulrush	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Typha latifolia	common cattail	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Table 5.2. Abundance Index by species inside the Stoddard Bay Habitat Rehabilitation and Enhancement Project area of Pool 8, Upper Mississippi River System.

Scientific name	Common name	1998 (n = 27)	1999 (n = 29)	2000 (n = 27)	2001 (n = 35)	2002 (n = 35)
All submersed species		**7.4 ± 0.8**	**17.4 ± 1.5**	**16.0 ± 0.8**	**17.7 ± 1.1**	**24.8 ± 0.8**
Ceratophyllum demersum	coontail	0.0 ± 0.0	1.6 ± 0.4	5.0 ± 0.7	10.6 ± 0.7	19.5 ± 1.0
Elodea canadensis	Canadian waterweed	3.4 ± 0.5	12.5 ± 1.1	13.4 ± 0.8	15.2 ± 1.3	18.8 ± 0.9
Heteranthera dubia	water stargrass	4.3 ± 0.6	12.0 ± 1.4	11.3 ± 0.8	10.3 ± 0.9	11.0 ± 0.6
Myriophyllum spicatum	Eurasian watermilfoil	0.4 ± 0.2	2.3 ± 0.5	5.1 ± 0.6	6.8 ± 0.8	11.0 ± 0.7
Najas flexilis	nodding waternymph	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.4	1.0 ± 0.4	0.0 ± 0.0
Potamogeton crispus	curly pondweed	0.0 ± 0.0	1.5 ± 0.3	1.3 ± 0.4	3.5 ± 0.6	0.9 ± 0.2
Potamogeton foliosus/pusillus	leafy/small pondweed	0.0 ± 0.0	0.0 ± 0.0	2.9 ± 0.4	2.9 ± 0.5	2.6 ± 0.5
Potamogeton nodosus	longleaf pondweed	0.7 ± 0.3	0.0 ± 0.0	0.4 ± 0.1	1.2 ± 0.4	0.9 ± 0.4
Potamogeton richardsonii	Richardson's pondweed	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2
Potamogeton zosteriformis	flatstem pondweed	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2
Stukenia pectinatus	sago pondweed	2.7 ± 0.6	1.8 ± 0.6	2.2 ± 0.5	2.6 ± 0.6	1.9 ± 0.4
Vallisneria americana	American wildcelery	2.2 ± 0.4	1.3 ± 0.5	8.9 ± 0.7	10.3 ± 0.8	10.5 ± 0.8
All rooted floating-leaf species		**0.0 ± 0.0**	**0.0 ± 0.0**	**2.2 ± 0.6**	**7.6 ± 1.0**	**24.8 ± 2.9**
Nelumbo lutea	American lotus	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 0.6	5.0 ± 0.9	18.3 ± 2.6
Nymphaea odorata	white waterlily	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.9 ± 0.8	5.2 ± 2.1
All emergent species		**0.0 ± 0.0**	**0.0 ± 0.0**	**0.0 ± 0.0**	**0.0 ± 0.0**	**5.2 ± 1.6**
Sagittaria latifolia	broadleaf arrowhead	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.9 ± 1.6
Sagittaria rigida	stiff arrowhead	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.7

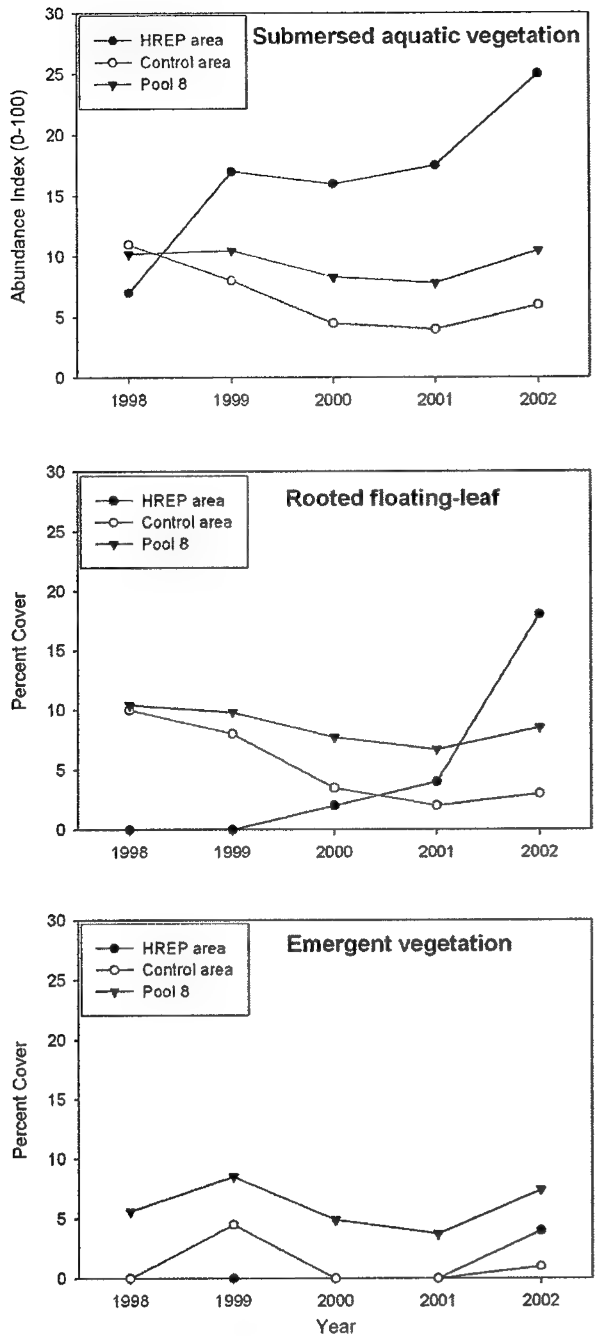


Figure 5.2. Abundance index for submersed, rooted floating-leaf, and emergent aquatic vegetation in the Stoddard Bay Habitat Rehabilitation and Enhancement Project (HREP) and control area, Upper Mississippi River.

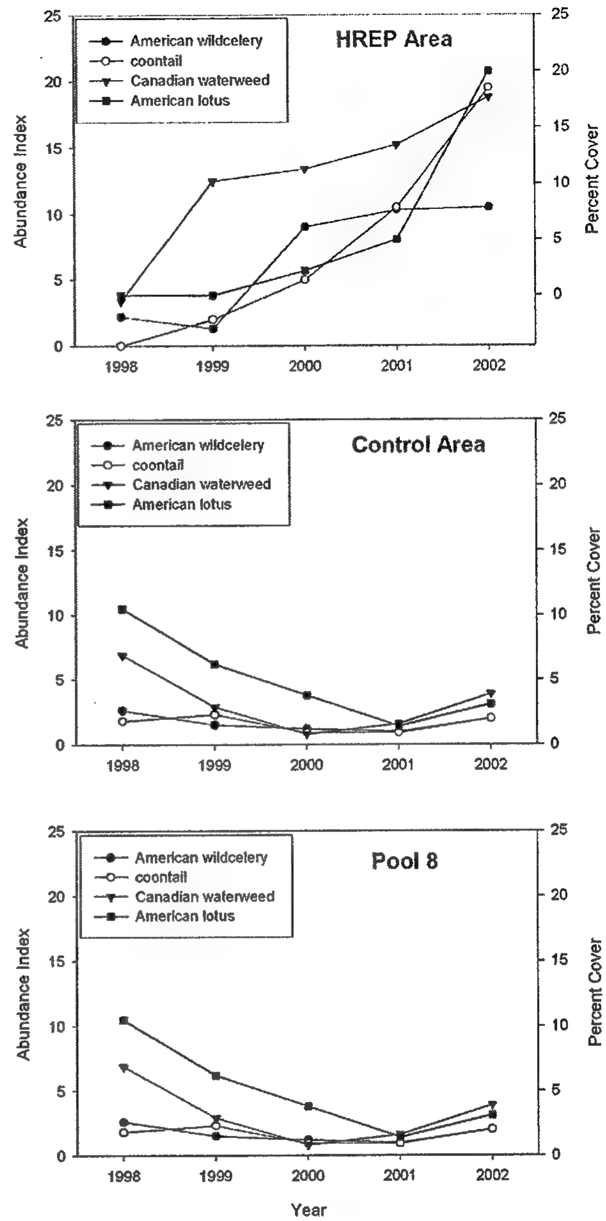


Figure 5.3. Abundance index of American wildcelery (*Vallisneria americana* Michx.), coontail (*Ceratophyllum demersum* L.), and Canadian waterweed (*Elodea canadensis* Michx.) and percent cover of American lotus (*Nelumbo luteo* Willd.) in the Stoddard Bay Habitat Rehabilitation and Enhancement Project (HREP) area, control area, and Pool 8, Upper Mississippi River.

Chapter 6: Summary

Based on our analyses presented in Chapters 2–5, we conclude:

- Submersed aquatic vegetation beds in the Upper Mississippi River System were present in higher frequency in areas less influenced by flows from the main channels. Deeper water, faster velocities, and increased suspended solids are related to the distribution and abundance of SAV in the UMRS.
- Within a navigation pool, the mid- and lower sections are better habitat than the tailwater section for SAV. Slower velocities and shallower water may be two factors contributing to this difference.
- The dynamics of submersed aquatic vegetation from 1991 to 2002 varied among the river reaches monitored by the LTRMP. Our data revealed that SAV declined steadily from 1991 to 2002 in upper Pool 4 and only a small fraction of SAV beds remained there through 2002. The SAV in lower Pool 4 experienced a decline from 1991 to 1996, followed by a moderate recovery still evident in 2002.
- The LTRMP data in Pool 8 documented a major setback in summer 1991 in the aftermath of the 1987–89 basin-wide drought as well as a process of recovery lasting throughout the 1990s.
- The SAV growth in Pool 13 displayed a high degree of stability over the period of record and high degree of resilience against occasional summer declines.
- Presence of SAV in Pool 26 and La Grange Pool was extremely rare.
- Few SAV beds were present in the backwaters of the Illinois River within the lower 12 miles of the Alton Pool.
- Five species out of 56 recorded in the five outpools were not among the 121 species recorded in the key pools.
- A detrended correspondence analysis indicated the outpools were within the range of variation among the key pools. None of the outpools we sampled in 2002 were found to be drastically different from all the key pools, which suggests the LTRMP key pools represent a wide spectrum of UMRS habitats.
- The longitudinal pattern of SAV distribution in the UMRS is strongly correlated with water turbidity and water level fluctuation (r^2=.82). Pools with clearer water and less fluctuating water levels supported better vegetation growth. Turbidity was a stronger predictor of SAV abundance than water level fluctuation.
- The environmental engineering project completed in 1998 at Stoddard Bay in Pool 8 of the Upper Mississippi River has effectively promoted plant recolonization. After four growing seasons, *Ceratophyllum demersum* L. and *Elodea canadensis* Michx. dominated the water column in deeper (>0.5 m) regions and *Nelumbo lutea* Willd. dominated the water surface in shallower (<0.5 m) regions. *Ceratophyllum demersum* and *N. lutea* continued expanding their distribution through 2002.

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Appendix A. Total number of points sampled along transects by pool and year, 1991–2002

Table A-1. Upper Pool 4 (above Lake Pepin).

Year	Big Lake		Rice Lake/Big Lake Bay		Catherine Pass		Dead Slough Lake	
	Sp[a]	Su[b]	Sp	Su	Sp	Su	Sp	Su
1991	181	177	49	72	77	74	98	93
1992	133	123	58	55	76	76	130	129
1993	152	159	64	56	78	70	133	115
1994	156	149	81	53	78	62	140	136
1995	171	158	90	77	85	80	162	135
1996	182	160	85	80	80	85	136	136
1997	167	148	91	78	88	88	142	143
1998	157	153	71	67	71	74	134	133
1999	165	159	79	79	80	80	136	136
2000	ns[c]	167	ns	79	80	ns	133	ns

[a]Spring

[b]Summer

[c]Not sampled

Table A-2. Lower Pool 4 (below Lake Pepin).

Year	Goose Lake		Mud Lake		Lower Peterson Lake		Upper Peterson Lake		Robinson Lake	
	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su
1991	25	25	63	58	94	119	70	61	199	179
1992	26	23	55	56	109	156	71	51	198	168
1993	28	24	57	51	118	132	56	58	187	211
1994	26	27	59	53	115	132	69	72	223	221
1995	31	28	61	68	130	128	77	72	233	227
1996	30	28	63	55	104	128	55	53	228	225
1997	30	28	57	55	127	118	80	80	220	205
1998	25	24	57	54	130	112	69	75	204	213
1999	26	27	55	55	122	122	69	59	210	198
2000	27	ns	55	ns	ns	122	ns	71	ns	203

Table A-3. Pool 8.

Year	Blue Lake		Boomerang Island		Goose Island		Horseshoe Island		Lawrence Lake		Shady Maple		Stoddard		Target Lake	
	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su
1991	ns	ns	ns	ns	ns	80	ns	40	258	195	24	30	ns	ns	102	79
1992	ns	ns	ns	ns	111	113	75	83	261	398	106	105	ns	47	105	259
1993	ns	122	ns	75	114	114	75	82	247	435	114	101	48	46	169	298
1994	112	110	107	102	112	112	76	78	392	407	100	105	47	47	298	278
1995	124	118	104	104	118	113	82	80	422	386	102	104	48	47	291	298
1996	126	118	104	104	112	114	85	82	421	417	102	90	50	48	293	279
1997	126	116	104	104	119	114	90	85	426	402	107	102	50	51	287	286
1998	134	132	104	104	111	115	83	81	434	441	102	106	50	50	290	292
1999	135	123	104	104	117	109	82	90	418	374	105	101	49	50	298	286
2000	ns	135	ns	104	ns	111	ns	88	ns	405	ns	101	ns	50	ns	295
2001	ns	ns	ns	104	ns	78	ns	84	ns	318	ns	100	ns	ns	ns	200

Table A-4. Pool 13.

Year	Brown's Lake		Johnson Creek		Johnson Creek Levee		Pomme de Terre		Potter's Marsh		Savannah Bay		Spring Lake	
	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su
1991	194	235	ns	30	55	40	52	59	49	41	ns	120	ns	99
1992	280	354	40	56	81	73	69	81	71	41	146	148	126	136
1993	325	308	53	59	88	82	78	77	77	75	135	150	149	130
1994	379	390	41	59	83	89	74	82	77	101	151	134	136	176
1995	367	458	60	70	116	107	75	71	87	94	137	138	176	173
1996	338	357	59	65	113	102	75	75	96	92	142	139	162	166
1997	384	421	61	65	123	122	71	81	101	129	143	141	174	181
1998	431	424	66	67	108	114	68	85	110	132	144	143	153	179
1999	450	451	72	67	126	124	87	88	126	126	151	151	190	189
2000	164	455	67	68	ns	124	87	86	ns	126	151	151	189	190

Table A-5. Alton Pool.

Year	Calhoun Point		Fuller Lake		Stump Lake		Swan Lake	
	Sp	Su	Sp	Su	Sp	Su	Sp	Su
1991	276	137	ns	ns	196	ns	308	80
1992	157	157	32	ns	168	ns	291	282
1993	157	156	29	32	174	194	291	146
1994	155	ns	50	ns	169	ns	276	ns
1995	82	86	29	29	166	155	161	159
1996	156	27	29	37	126	102	ns	ns
1997	157	77	29	ns	175	ns	133	133
1998	159	157	29	29	170	174	282	292
1999	157	150	29	41	168	175	292	292
2000	155	ns	34	ns	171	ns	291	ns

Table A-6. La Grange Pool.

Year	Banner Marsh		Grape Island		Point Lake		Spring Lake	
	Sp	Su	Sp	Su	Sp	Su	Sp	Su
1991	13	13	ns	ns	20	20	105	99
1992	16	16	13	9	20	21	87	86
1993	18	16	21	ns	28	26	144	143
1994	26	22	18	21	25	26	147	146
1995	24	24	21	15	25	26	ns	146
1996	16	17	ns	12	22	22	51	78
1997	14	12	16	16	24	25	119	99
1998	18	18	16	18	25	23	90	92
1999	20	20	16	16	25	25	98	90
2000	18	17	18	18	25	22	100	90

Appendix B. Percent frequency of occurrence of submersed aquatic vegetation by year, sampling strata, and pool for stratified random sampling 1998–2002, Long Term Resource Monitoring Program, Upper Mississippi River System.

	1998			1999			2000			2001			2002		
Stratum	Frq[a]	Std[b]	n[c]	Frq	Std	n	Frq	Std	n	Frq	Std	n	Frq	Std	n
Pool 4 – Isolated Backwater	84.4	6.5	32	81.3	7.0	32	81.3	7.0	32	76.0	6.1	50	83.3	6.9	30
Upper Pool 4[d] – Main Channel Border	0.0	0.0	9	16.7	11.2	12	3.3	3.3	30	3.3	3.3	30	3.3	3.3	30
Upper Pool 4 – Secondary Channel	4.3	3.0	47	0.0	0.0	61	0.0	0.0	40	0.0	0.0	40	5.0	3.5	40
Upper Pool 4 – Contiguous Backwater	32.4	5.5	74	29.3	5.3	75	18.0	3.9	100	14.0	3.5	100	16.0	3.7	100
Upper Pool 4 – Lake Pepin	21.1	5.4	57	16.9	4.7	65	14.7	4.1	75	5.3	2.6	75	8.0	3.2	75
Lower Pool 4[d] – Main Channel Border	10.8	5.2	37	20.8	5.9	48	22.5	6.7	40	22.5	6.7	40	20.0	6.4	40
Lower Pool 4 – Secondary Channel	35.4	6.0	65	37.3	6.3	59	45.0	6.5	60	31.7	6.1	60	25.0	5.6	60
Lower Pool 4 – Contiguous Backwater	68.8	3.7	157	66.3	3.8	160	64.2	3.6	179	71.0	3.4	176	67.2	3.5	180
Lower Pool 4 – Lake Pepin	6.9	4.8	29	8.6	4.8	35	46.7	5.8	75	41.3	5.7	75	25.3	5.1	75
Pool 8 – Main Channel Border	18.9	5.4	53	25.7	5.3	70	30.3	4.6	99	24.0	4.3	100	17.0	3.8	100
Pool 8 – Secondary Channel	35.5	5.0	93	36.0	4.8	100	32.5	4.3	120	22.5	3.8	120	29.2	4.2	120
Pool 8 – Impounded	33.5	3.6	170	44.9	3.3	225	34.7	3.2	225	36.9	3.2	225	47.3	3.3	224
Pool 8 – Contiguous Backwater	82.0	2.9	172	92.4	2.0	172	74.9	3.3	175	76.0	3.2	175	76.4	3.2	174
Pool 8 – Isolated Backwater	96.4	3.6	28	92.9	5.0	28	93.3	4.6	30	92.0	3.9	50	88.5	6.4	26
Pool 13 – Main Channel Border	8.1	3.5	62	11.4	3.8	70	14.3	4.2	70	10.0	3.6	70	7.1	3.1	70
Pool 13 – Secondary Channel	14.5	4.5	62	10.0	3.6	70	4.3	2.4	70	14.3	4.2	70	10.0	3.6	70
Pool 13 – Impounded	42.6	3.4	209	42.4	3.4	210	40.5	3.4	210	38.3	3.4	209	44.5	3.4	209
Pool 13 – Contiguous Backwater	52.4	3.8	170	51.8	3.8	170	58.1	3.5	198	55.6	3.5	198	51.5	3.5	200
Pool 13 – Isolated Backwater	71.4	8.7	28	56.7	9.2	30	53.3	9.3	30	57.6	6.5	59	66.7	8.8	30
Pool 26 – Main Channel Border	0.0	0.0	121	0.0	0.0	137	0.0	0.0	50	0.0	0.0	49	0.0	0.0	50
Pool 26 – Secondary Channel	0.0	0.0	84	0.0	0.0	90	0.0	0.0	50	0.0	0.0	50	0.0	0.0	50
Pool 26 – Impounded	0.0	0.0	27	1.3	1.3	80	0.0	0.0	40	0.0	0.0	40	0.0	0.0	40
Pool 26 – Contiguous Backwater	2.0	2.0	50	0.0	0.0	80	0.0	0.0	80	0.0	0.0	80	0.0	0.0	80
Pool 26 – Isolated Backwater	3.3	3.3	30	0.0	0.0	50	2.4	2.4	42	0.0	0.0	60	1.8	1.8	57
Lower Alton Pool – Main Channel Border	0.0	0.0	47	2.0	2.0	50	0.0	0.0	40	0.0	0.0	40	0.0	0.0	40
Lower Alton Pool – Isolated Backwater	16.9	3.0	160	1.3	0.9	160	14.7	3.7	95	6.4	2.5	94	6.0	2.4	100
La Grange Pool – Main Channel Border	0.0	0.0	83	0.0	0.0	120	0.0	0.0	80	0.0	0.0	78	0.0	0.0	80
La Grange Pool – Secondary Channel	0.0	0.0	29	0.0	0.0	40	0.0	0.0	50	0.0	0.0	50	0.0	0.0	50
La Grange Pool – Contiguous Backwater	0.0	0.0	172	0.0	0.0	190	0.0	0.0	100	0.0	0.0	100	0.0	0.0	100
La Grange Pool – Isolated Backwater	0.0	0.0	179	0.0	0.0	187	0.0	0.0	138	0.0	0.0	129	0.0	0.0	139
La Grange Pool – Floodplain Lake	ns[e]	ns	ns	ns	ns	ns	80.7	5.3	57	77.2	5.6	57	79.7	5.3	59

[a]Percent frequency of occurrence
[b]Standard error
[c]Number of sites
[d]For analysis, Pool 4 was divided into upper (above river mile 775) and lower (below river mile 775) sections
[e]Not sampled

Appendix C. Percent frequency of occurrence by species for Pools 4, 5, and 7 based on 2002 stratified random sampling, Long Term Resource Monitoring Program, Upper Mississippi River System.

		Upper Pool 4[a]		Lower Pool 4[a]		Pool 5		Pool 7	
		n = 245		n = 355		n = 404		n = 392	
Common name	**Scientific name**	**Frq[b]**	**Std[c]**	**Frq**	**Std**	**Frq**	**Std**	**Frq**	**Std**
Submersed vegetation									
bladderwort, common	*Utricularia macrorhiza* Le Conte	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.4
buttercup	*Ranunculus* spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3
chara	*Chara* spp.	0.0	0.0	0.3	0.3	0.2	0.2	3.2	0.9
coontail	*Ceratophyllum demersum* L.	1.9	0.9	24.4	2.3	12.0	1.6	32.4	2.4
pondweed, curly	*Potamogeton crispus* L.	0.0	0.0	10.5	1.6	3.7	0.9	3.2	0.9
pondweed, flatstem	*P. zosteriformis* Fern.	0.0	0.0	7.3	1.4	2.7	0.8	19.0	2.0
pondweed, horned	*Zannichellia palustris* L.	0.0	0.0	0.3	0.3	0.4	0.3	0.0	0.0
pondweed, leafy/small	*P. foliosus* Raf./*P.* L.	0.5	0.5	13.0	1.8	5.7	1.2	11.6	1.6
pondweed, longleaf	*P. nodosus* Poir.	0.3	0.3	3.7	1.0	2.8	0.8	2.5	0.8
pondweed, Richardson's	*P. richardsonii* (Benn.) Rydb.	0.0	0.0	0.0	0.0	0.2	0.2	8.5	1.4
pondweed, sago	*Stuckenia pectinatus* (L.) Boerner	9.1	1.8	8.6	1.5	10.3	1.5	6.4	1.2
stargrass, water	*Heteranthera dubia* (Jacq.) Mac.	0.0	0.0	24.0	2.3	9.8	1.5	24.9	2.2
watermilfoil, Eurasian	*Myriophyllum spicatum* L.	0.0	0.0	19.2	2.1	10.5	1.5	21.0	2.1
watermilfoil, northern	*M. sibiricum* Komarov	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0
waternymph, nodding	*Najas flexilis* (Willd.) Rostk. and Schmidt	0.3	0.3	4.2	1.1	0.4	0.3	5.4	1.1
waterweed, Canadian	*Elodea canadensis* Michx.	0.5	0.5	21.6	2.2	11.4	1.6	31.6	2.4
wildcelery	*Vallisneria americana* Michx.	0.0	0.0	28.6	2.4	9.1	1.4	43.5	2.5
Rooted floating-leaf vegetation									
lotus, American	*Nelumbo lutea* Willd.	0.0	0.0	3.1	0.9	4.6	1.0	8.0	1.4
pond-lily, yellow	*Nuphar variegata* Dur.	0.0	0.0	0.3	0.3	0.4	0.3	0.1	0.2
waterlily, white	*Nymphaea odorata* Ait.	1.3	0.7	12.5	1.8	10.0	1.5	9.2	1.5
Emergent vegetation									
arrowhead, broadleaf	*Sagittaria latifolia* Willd.	1.1	0.7	5.8	1.2	0.4	0.3	3.6	0.9
arrowhead, stiff	*Sagittaria rigida* Pursh	0.0	0.0	7.3	1.4	0.0	0.0	8.8	1.4
bulrush, river	*Schoenoplectus fluviatilis* (Torr) MT Strong	2.4	1.0	1.2	0.6	0.0	0.0	0.4	0.3
bulrush, softstem	*Schoenoplectus tabernaemontani* (K.C. Gelm) Palla	0.8	0.6	0.7	0.5	0.6	0.4	0.3	0.3
burreed, giant	*Sparganium eurycarpum* Engelm x Gray	0.0	0.0	2.6	0.8	1.8	0.7	1.8	0.7
canarygrass, reed	*Phalaris arundinacea* L.	0.3	0.3	1.3	0.6	1.2	0.6	0.3	0.3
cattail, broadleaf	*Typha latifolia* L.	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.2
cattail, narrowleaf	*Typha angustifolia* L.	0.3	0.3	0.0	0.0	0.2	0.2	0.1	0.2
cutgrass, rice	*Leersia oryzoides* (L.) Sw.	0.3	0.3	1.0	0.5	0.2	0.2	0.4	0.3
horsetail	*Equisetum* spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
loosestrife, purple	*Lythrum salicaria* L.	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.0
pickerelweed	*Pontederia cordata* L.	0.0	0.0	0.9	0.5	0.2	0.2	2.6	0.8
rice, wild	*Zizania aquatica* L.	0.0	0.0	1.2	0.6	0.0	0.0	6.6	1.3
smartweed, dotted	*Polygonum punctatum* Ell.	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3
smartweed, water	*Polygonum amphibium* L.	0.0	0.0	0.2	0.3	0.0	0.0	0.7	0.4
spikerush	*Eleocharis* spp.	0.0	0.0	0.6	0.4	0.0	0.0	0.2	0.3
willow, sandbar	*Salix exigua* Nutt.	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0

[a]For analysis, Pool 4 was divided into upper (above river mile 775) and lower (below river mile 775) sections

[b]Percent frequency of occurrence

[c]Standard error

Appendix D. Percent frequency of occurrence by species for Pool 11 in 2001 and Pools 8, 12, and 13 based on 2002 stratified random sampling, Long Term Resource Monitoring Program, Upper Mississippi River System.

		Pool 8		Pool 11		Pool 12		Pool 13	
		n = 644		*n* = 568		*n* = 404		*n* = 579	
Common name	**Scientific name**	**Frq**[a]	**Std**[b]	**Frq**	**Std**	**Frq**	**Std**	**Frq**	**Std**
Submersed vegetation									
bladderwort, common	*Utricularia macrorhiza* Le Conte	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
chara	*Chara* spp.	0.5	0.3	0.3	0.2	0.0	0.0	0.6	0.3
coontail	*Ceratophyllum demersum* L.	28.0	1.8	9.1	1.2	9.2	1.4	24.5	1.8
pondweed, curly	*Potamogeton crispus* L.	10.6	1.2	0.8	0.4	0.6	0.4	9.1	1.2
pondweed, flatstem	*P. zosteriformis* Fern.	7.7	1.1	0.7	0.3	0.0	0.0	0.5	0.3
pondweed, horned	*Zannichellia palustris* L.	0.1	0.1	0.0	0.0	0.0	0.0	0.7	0.3
pondweed, leafy/small	*P. foliosus* Raf./*P.* L.	12.1	1.3	1.1	0.4	0.8	0.4	8.7	1.2
pondweed, longleaf	*P. nodosus* Poir.	3.8	0.8	0.8	0.4	3.9	1.0	4.4	0.9
pondweed, Richardson's	*P. richardsonii* (Benn.) Rydb.	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0
pondweed, sago	*Stuckenia pectinatus* (L.) Boerner	14.5	1.4	9.2	1.2	6.7	1.2	22.8	1.8
stargrass, water	*Heteranthera dubia* (Jacq.) MacM.	28.3	1.8	0.7	0.3	4.4	1.0	9.5	1.2
watermilfoil, Eurasian	*Myriophyllum spicatum* L.	16.9	1.5	2.3	0.6	2.8	0.8	14.1	1.5
waternymph, brittle	*Najas minor* All.	0.0	0.0	0.0	0.0	0.2	0.2	6.3	1.0
waternymph, nodding	*N. flexilis* (Willd.) Rostk. & Schmidt	1.6	0.5	0.3	0.2	0.0	0.0	0.0	0.0
waternymph, southern	*N. guadalupensis* (Spreng.) Magnus	0.0	0.0	1.4	0.5	0.0	0.0	2.1	0.6
waterweed, Canadian	*Elodea canadensis* Michx.	31.0	1.8	0.9	0.4	1.1	0.5	7.5	1.1
wildcelery	*Vallisneria americana* Michx.	19.3	1.6	2.1	0.6	1.7	0.6	16.2	1.5
Rooted floating-leaf vegetation									
lotus, American	*Nelumbo lutea* Willd.	6.9	1.0	5.8	1.0	11.8	1.6	21.3	1.7
pond-lily, yellow	*Nuphar variegata* Dur.	1.1	0.4	0.2	0.2	0.0	0.0	0.0	0.0
waterlily, white	*Nymphaea odorata* Ait.	12.7	1.3	4.4	0.9	3.0	0.8	5.6	1.0
Emergent vegetation									
arrowhead, broadleaf	*Sagittaria latifolia* Willd.	8.2	1.1	2.6	0.7	5.7	1.2	4.5	0.9
arrowhead, stiff	*Sagittaria rigida* Pursh	7.1	1.0	0.5	0.3	0.8	0.4	0.1	0.1
bulrush, river	*Schoenoplectus fluviatilis* (Torr) MT Strong	1.1	0.4	0.2	0.2	1.8	0.7	0.4	0.2
bulrush, softstem	*Schoenoplectus tabernaemontani* (K.C. Gelm) Palla	1.7	0.5	0.0	0.0	0.0	0.0	0.4	0.3
burreed, giant	*Sparganium eurycarpum* Engelm x Gray	1.5	0.5	0.0	0.0	0.4	0.3	0.2	0.2
canarygrass, reed	*Phalaris arundinacea* L.	1.6	0.5	0.3	0.2	0.8	0.4	0.5	0.3
cattail, broadleaf	*Typha latifolia* L.	0.0	0.0	0.0	0.0	0.4	0.3	0.0	0.0
cutgrass, rice	*Leersia oryzoides* (L.) Sw.	3.0	0.7	0.3	0.2	2.4	0.8	1.0	0.4
dock	*Rumex* spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
loosestrife, purple	*Lythrum salicaria* L.	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.3
pickerelweed	*Pontederia cordata* L.	0.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0
reed, common	*Phragmites australis* (Cav.) Trin. ex Steud.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
rice, wild	*Zizania aquatica* L.	1.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0
smartweed, Pennsylvania	*Polygonum pensylvanicum* L.	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
smartweed, water	*Polygonum amphibium* L.	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
spikerush	*Eleocharis* spp.	0.5	0.3	0.0	0.0	0.0	0.0	0.1	0.1

[a]Percent frequency of occurrence
[b]Standard error

Appendix E. Percent frequency of occurrence by species for Pool 26 and Alton Pool based on 2002 stratified random sampling, Long Term Resource Monitoring Program, Upper Mississippi River System.

		Pool 26		Lower Alton Pool		Upper Alton Pool	
		n = 277		*n* = 140		*n* = 408	
Common name	**Scientific name**	**Frq[a]**	**Std[b]**	**Frq**	**Std**	**Frq**	**Std**
Submersed vegetation							
pondweed, leafy	*Potamogeton foliosus* Raf	0.0	0.0	0.8	0.8	0.0	0.0
pondweed, longleaf	*P. nodosus* Poir.	0.0	0.0	0.8	0.8	0.0	0.0
pondweed, sago	*Stuckenia pectinatus* (L.) Boerner	0.2	0.3	3.4	1.5	0.0	0.0
stargrass, water	*Heteranthera dubia* (Jacq.) MacM.	0.0	0.0	1.7	1.1	0.0	0.0
waternymph, southern	*Najas guadalupensis* (Spreng.) Magnus	0.0	0.0	3.4	1.5	0.0	0.0
Rooted floating-leaf vegetation							
lotus, American	*Nelumbo lutea* Willd.	0.4	0.4	5.0	1.9	0.0	0.0
primrose-willow, floating	*Ludwigia peploides* (Kunth) Raven	1.2	0.7	0.8	0.8	0.0	0.0
waterhyssop, disk	*Bacopa rotundifolia* (Michx.) Wettst.	0.8	0.5	0.0	0.0	0.0	0.0
Emergent vegetation							
amaranth, roughfruit	*Amaranthus tuberculatus* (Moq.) Sauer	0.4	0.4	5.9	2.0	1.2	0.5
arrowhead, arumleaf	*Sagittaria cuneata* Sheldon	0.2	0.3	4.2	1.7	0.0	0.0
arrowhead, broadleaf	*Sagittaria latifolia* Willd.	2.1	0.9	0.8	0.8	0.7	0.4
ash, green	*Fraxinus pennsylvanica* Marsh	0.3	0.3	0.8	0.8	0.4	0.3
barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	1.1	0.6	7.6	2.2	1.8	0.7
barnyardgrass, rough	*Echinochloa muricata* (Beauv) Fern.	0.3	0.3	0.0	0.0	0.0	0.0
beggarticks, bearded	*Bidens aristosa* (Michx.) Britt.	0.3	0.3	0.0	0.0	0.0	0.0
buttonbush, common	*Cephalanthus occidentalis* L.	1.2	0.7	0.8	0.8	0.1	0.2
bulrush, river	*Schoenoplectus fluviatilis* (Torr) Strong	2.0	0.8	0.0	0.0	0.0	0.0
cockleburr, rough	*Xanthium strumarium* L.	0.3	0.3	2.5	1.3	1.6	0.6
cottonwood, eastern	*Populus deltoides* Bartr. x Marsh.	0.4	0.4	0.8	0.8	0.3	0.3
crabgrass	*Digitaria* spp.	0.0	0.0	2.5	1.3	0.0	0.0
cucumber, oneseed burr	*Sicyos angulatus* L.	0.5	0.4	0.0	0.0	0.0	0.0
cutgrass, rice	*Leersia oryzoides* (L.) Sw.	0.0	0.0	1.7	1.1	0.0	0.0
daisy, false	*Eclipta prostrata* (L.) L.	0.3	0.3	0.0	0.0	0.0	0.0
elm, American	*Ulmus americana* L.	0.0	0.0	0.0	0.0	0.4	0.3
flatsedge, redroot	*Cyperus erythrorhizos* Muhl.	2.3	0.9	5.9	2.0	1.2	0.5
flatsedge, strawcolored	*Cyperus strigosus* L.	0.2	0.3	0.0	0.0	0.0	0.0
dayflower, climbing	*Commelina diffusa* Burm. f.	0.3	0.3	0.0	0.0	0.0	0.0
fogfruit, lanceleaf	*Phyla lanceolata* (Michx.) Greene	1.0	0.6	0.0	0.0	0.0	0.0
grape, graybark	*Vitis cinerea* (Engelm.) Millard	0.0	0.0	0.0	0.0	0.3	0.3
grass, coast cockspur	*Echinochloa walteri* (Pursh) Heller	0.0	0.0	0.8	0.8	0.0	0.0
groundcherry	*Physalis* spp.	0.1	0.2	0.0	0.0	0.0	0.0
lovegrass, tufted	*Eragrostis pectinacea* (Michx.) Nees. ex Steud.	0.0	0.0	0.0	0.0	1.2	0.5
maple, silver	*Acer saccharinum* L.	2.6	1.0	0.0	0.0	0.3	0.3
milkweed, swamp	*Asclepias incarnata* L.	1.0	0.6	0.0	0.0	0.0	0.0
nettle, false	*Boehmeria cylindrica* (L.) Sw.	0.1	0.2	1.7	1.1	0.0	0.0
paspalum, horsetail	*Paspalum fluitans* (Ell.) Kunth	0.2	0.3	0.0	0.0	0.0	0.0
persimmon, common	*Diospyros virginiana* L.	0.2	0.3	0.0	0.0	0.0	0.0
rosemallow, halberdleaf	*Hibiscus laevis* All.	0.5	0.4	0.8	0.8	0.0	0.0
rush, common	*Juncus effuses* L.	0.2	0.3	0.0	0.0	0.0	0.0
sedge	*Carex* spp.	0.1	0.2	0.0	0.0	0.0	0.0
smartweed, Pennsylvania	*Polygonum pensylvanicum* L.	0.5	0.4	0.0	0.0	0.1	0.2
smartweed, swamp	*Polygonum hydropiperoides* Michx.	2.9	1.0	2.5	1.3	1.2	0.5
smartweed, water	*Polygonum amphibium* L.	0.0	0.0	0.8	0.8	0.0	0.0
sprangletop, Amazon	*Leptochloa panicoides* (J Presl) AS Hitchc	2.9	1.0	4.2	1.7	1.2	0.5
sprangletop, bearded	*Leptochloa fusca* (L.) Kunth spp. *fascicularis* (Lam.) N. Snow	0.0	0.0	0.8	0.8	0.0	0.0
stonecrop, ditch	*Penthorum sedoides* L.	0.8	0.6	0.0	0.0	0.0	0.0
swampprivet, eastern	*Forestiera acuminata* (Michx.) Poir.	0.0	0.0	0.8	0.8	0.0	0.0
whitestar	*Ipomoea lacunose* L.	0.5	0.4	2.5	1.3	0.0	0.0
willow, black	*Salix nigra* Marsh.	0.3	0.3	0.0	0.0	0.6	0.4

[a]Percent frequency of occurrence

[b]Standard error

Appendix F. Percent frequency of occurrence by species for La Grange Pool based on 2002 stratified random sampling, Long Term Resource Monitoring Program, Upper Mississippi River System.

		La Grange Pool		La Grange Floodplain Lakes	
		n = 369		*n* = 59	
Common name	**Scientific name**	**Frq**[a]	**Std**[b]	**Frq**	**Std**
Submersed vegetation					
bladderwort, common	*Utricularia macrorhiza* Le Conte	0.0	0.0	11.9	4.2
chara	*Chara* spp.	0.0	0.0	11.9	4.2
coontail	*Ceratophyllum demersum* L.	0.0	0.0	57.6	6.5
pondweed, curly	*Potamogeton crispus* L.	0.0	0.0	5.1	2.9
pondweed, horned	*Zannichellia palustris* L.	0.0	0.0	6.8	3.3
pondweed, leafy/small	*P. foliosus* Raf./*P.* L.	0.0	0.0	8.5	3.7
pondweed, longleaf	*P. nodosus* Poir.	0.0	0.0	5.1	2.9
pondweed, sago	*Stuckenia pectinatus* (L.) Boerner	0.0	0.0	6.8	3.3
stargrass, water	*Heteranthera dubia* (Jacq.) MacM.	0.0	0.0	3.4	2.4
watermilfoil, Eurasian	*Myriophyllum spicatum* L.	0.0	0.0	72.9	5.8
watermilfoil, northern	*M. sibiricum* Komarov	0.0	0.0	10.2	4.0
waternymph, brittle	*Najas minor* All.	0.0	0.0	8.5	3.7
waternymph, nodding	*N. flexilis* (Willd.) Rostk. & Schmidt	0.0	0.0	10.2	4.0
Rooted floating—leaf vegetation					
lotus, American	*Nelumbo lutea* Willd.	1.9	0.7	25.4	5.7
primrose-willow, wingleaf	*Ludwigia decurrens* Walt.	0.3	0.3	0.0	0.0
waterlily, white	*Nymphaea odorata* Ait.	0.0	0.0	13.6	4.5
Emergent vegetation					
arrowhead, broadleaf	*Sagittaria latifolia* Willd.	0.4	0.3	0.0	0.0
millet, Japanese	*Echinochloa esculenta* (Braun) H Scholz	2.1	0.8	0.0	0.0

[a]Percent frequency of occurrence
[b]Standard error

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13. ABSTRACT (Maximum 200 words)
Aquatic vegetation data were collected in the Upper Mississippi River System (UMRS) under the Long Term Resource Monitoring Program (LTRMP). From 1991 to 2002, five reaches were surveyed every year (key pools), and another five reaches were surveyed once (outpools). The study design changed from a protocol involving sampling along transects (1991–2000) to a protocol incorporating stratified random sampling (1998–2002) with concurrent sampling under both protocols in 1998–2000. The frequency of occurrence of plants revealed no synchronous trends among three key pools (Pools 4, 8, and 13) supporting sizable submersed aquatic vegetation beds. Submersed aquatic vegetation in upper Pool 4 declined steadily between 1991 and 2002. Submersed aquatic vegetation in lower Pool 4 declined between 1991 and 1996 and thereafter recovered moderately. Submersed aquatic vegetation in Pool 8 increased between 1991 and 1999, which probably was a recovery process from a reported sudden collapse after the 1987–1989 drought. Submersed aquatic vegetation in Pool 13 demonstrated a high degree of stability during the period of monitoring despite drastic fluctuations between spring and summer sampling in some years. Water turbidity and water level fluctuation were strongly correlated with the longitudinal pattern of submersed aquatic vegetation distribution in the UMRS. Pools with clearer water and less fluctuating water levels supported more submersed aquatic vegetation. The LTRMP key pools represented a wide spectrum of the UMRS habitats. The habitat rehabilitation and enhancement project (HREP) at Stoddard Bay in Pool 8 effectively stimulated colonization by aquatic vegetation.

14. SUBJECT TERMS
Aquatic vegetation, rooted floating-leaf, Illinois River, key pools, Long Term Resource Monitoring Program, Upper Mississippi River, outpools, submersed vegetation

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